AD________

MP 4 - 70

TRACING SAND MOVEMENT IN THE LITTORAL ZONE: PROGRESS IN THE RADIOISOTOPIC SAND TRACER (RIST) STUDY

July 1968 - February 1969

by

David B. Duane

MISCELLANEOUS PAPER NO. 4 - 70

AUGUST 1970

U. S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING
RESEARCH CENTER

55

TRACING SAND MOVEMENT IN THE LITTORAL ZONE: PROGRESS IN THE RADIOISOTOPIC SAND TRACER (RIST) STUDY

July 1968 - February 1969

by

David B. Duane

MISCELLANEOUS PAPER NO. 4 - 70

AUGUST 1970

U. S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING RESEARCH CENTER

ABSTRACT

The Coastal Engineering Research Center, in cooperation with the Atomic Energy Commission, initiated a multiagency program to create a workable radioisotopic sand tracing (RIST) program. Tagging procedures, instrumentation, field surveys and data handling techniques were developed which permit collection and analysis of over 12,000 bits of information per hour over a survey track of approximately 18,000 feet. Data obtained can be considered as nearly synoptic observations of sediment transport in a single environmental zone or in adjacent beach, surf and offshore zones.

Studies at Surf, California, indicate that sand labeled with the radioisotope of gold 198-199 provides much more data for analysis of sediment movement than does sand labeled with xenon-133. Surveys conducted confirm that, in response to any given set of wave conditions, a very different rate of sediment movement occurs in the zones between the high water line and -15 feet mean lower low water. Because of these differences, tracing surveys confined solely to the foreshore or offshore zone produce data only partially indicative of transport in the zone of immediate concern to coastal engineers. While an accurate determination of sediment drift volume remains illusive, qualitative data on sediment movement useful for engineering purposes can be obtained on a scale heretofore unattainable.

FOREWORD

Since July 1966, the Coastal Engineering Research Center (CERC) has directed a multiagency program to develop a workable sand-tracing system capable of operating on the beach, in the surf zone, and offshore. The primary effort is toward the use of radioactive tracers to understand the mechanics, pattern and volume of sediment movement. Results to June 1968 were summarized in "Radioisotopic Sand Tracer Study, Point Conception, California", May 1969, by D. B. Duane and C. W. Judge. That report is now out of print; copies may be purchased from the Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22151. The catalog number is AD 690 804

This report was prepared by D. B. Duane, Chief, Geology Branch and RIST program director, under the general supervision of G. M. Watts, Chief, Engineering Development Division. It is part of Contract AT(49-11)-2988 (as modified) between the Atomic Energy Commission (AEC) and CERC. Work of the AEC is provided through the Oak Ridge National Laboratory (ORNL). Other participants in the present west coast studies are: U. S. Army Engineer District, Los Angeles, U. S. Army Mobility Equipment Command,

First Strategic Aerospace Division of the Air Force, U. S. Navy Pacific Missile Range, Nuclear Systems and Space Power Division, National Aeronautics and Space Administration (NASA), and Department of Water Resources, State of California.

The contributions of all participants in the program have been outstanding. Particular appreciation is expressed to the following:

O. M. Bizzell, Division of Isotope Development, AEC
T. B. Kerr, Nuclear Systems and Space Power Division, NASA
R. R. Baray, First Strategic Aerospace Division, Vandenberg AFB
E. Rhodes, U. S. Navy Pacific Missile Range
Colonel J. Irvine, Jr., Western Area Office, Los Angeles District
Hal Leeson, Department of Water Resources, State of California
J. H. Bittner, T. A. Bertin, and the field crews and technical personnel of the Los Angeles District.

This report has benefited from comments and suggestions from F. N. Case, E. H. Acree, and H. R. Brashear of ORNL, and C. W. Judge, P. A. Turner, and W. R. James of CERC.

At the time of publication, Lieutenant Colonel Edward M. Willis was Director of CERC: Joseph M. Caldwell was Technical Director.

NOTE: Comments on this paper are invited. Discussion will be published in the next issue of the CERC Bulletin.

This report is published under authority of Public Law 166, 79th Congress, approved July 31, 1945, as supplemented by Public Law 172, 88th Congress, approved November 7, 1963.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TRACING LITTORAL SAND MOVEMENT: RADIOISOTOPIC SAND TRACER (RIST) STUDY

Progress July 1968 - February 1969

Section I. INTRODUCTION

1. Background

In 1966, the U. S. Army Coastal Engineering Research Center (CERC), in cooperation with the Atomic Energy Commission (AEC), initiated a Radioisotopic Sand Tracer (RIST) Investigation of Littoral Transport around Point Conception, California. Program objectives were: (a) a study and selection of suitable radioisotope(s); (b) development of radiation detection equipment capable of operating on the beach and in the nearshore waters to depths of 100 feet; and (c) trace the movement of tagged sand in the littoral zone.

A major part of the development of hardware and tagging techniques was done by AEC's Oak Ridge National Laboratory (ORNL) at Oak Ridge, Tennessee. Other direct participants in the study in fiscal year 1969 were U. S. Navy Pacific Missile Range; U. S. Air Force First Strategic Aerospace Division; U. S. Army Engineer District Office in Los Angeles; U. S. Army Mobility Command; National Aeronautics and Space Administration; and the Division of Water Resources, State of California.

Results of this program through June 1968 have been summarized previously (Duane and Judge, 1969; Acree, et al, 1969). This paper is a report on progress of the program since June 1968, especially on various aspects of sediment movement on the beach and nearshore zone as depicted by experiments at Surf, California, during September-October 1968, and February 1969 (Figure 1).

Since 1968, results of several different field experiments in nuclide tracers have been published. Courtois and Monaco (1969) report on tests carried out along the French Mediterranean Coast in water 12 to 15 feet deep, using chromium 51 and iridium 95 as the tagging isotopes. The French experiment established sediment dispersal patterns over a period of 1 month.

The U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, recently completed a survey in the Houston Ship Channel (Hart, 1969). The isotope, gold-198, was mixed in solution with sediment at the site. The experiment lasted about 2 weeks.

Several studies using fluorescent tracers have been reported recently. Kennedy and Kouba (1968) in a U. S. Geological Survey (USGS) open-file report, present results of studies in sediment transport at Clear Creek, Colorado. At the University of Florida, the Department of Coastal and Oceanographic Engineering has been experimenting with

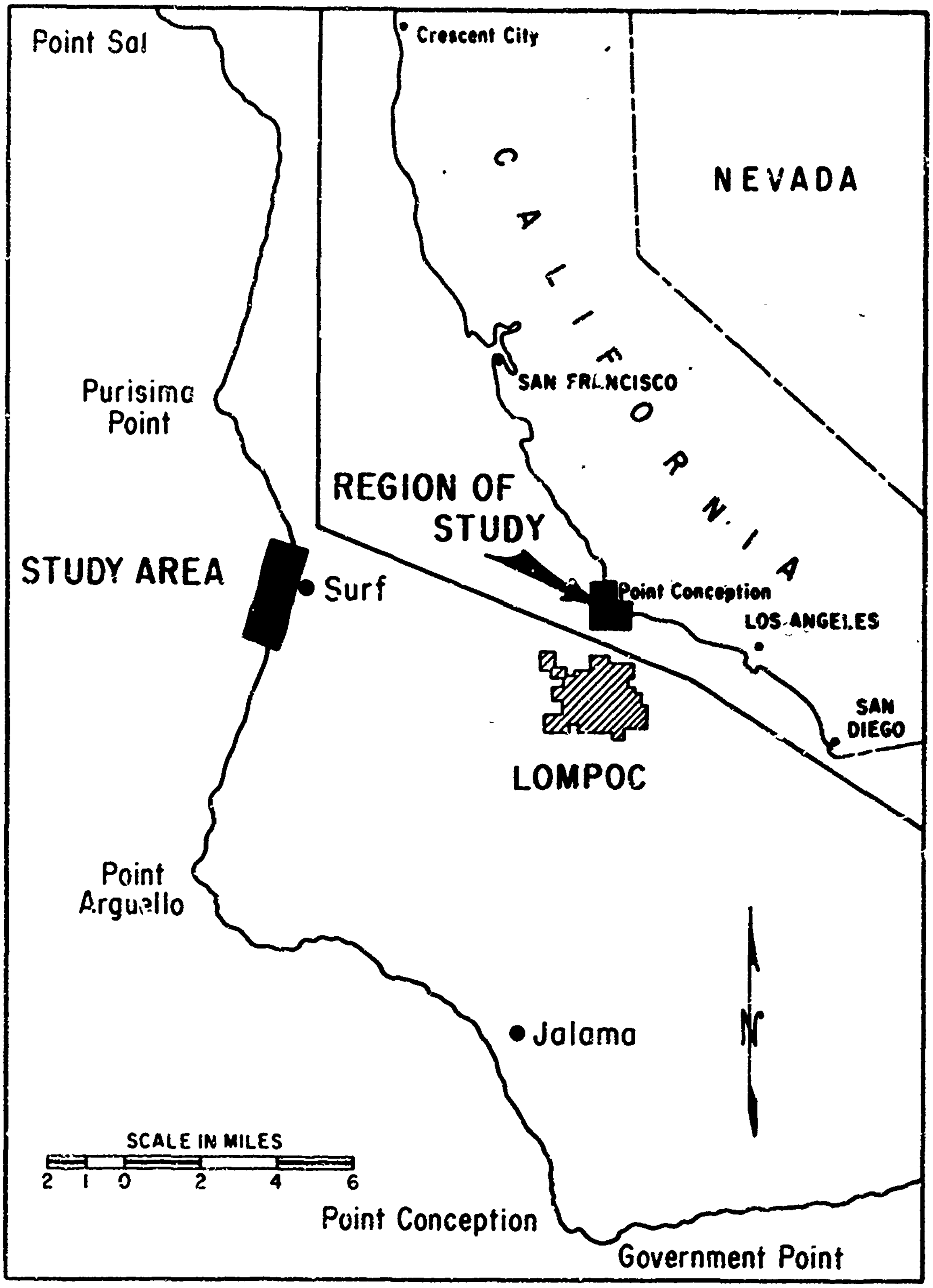


Figure 1. Study Area. Actual site of tracing operations was on Vandenberg Air Force Base property immediately north of Surf, California.

fluorescent tracing in the marine environment for several years. Results of recent studies, carried out on the east coast of Florida, are summarized by Stuiver and Purpura (1969). Komar (1969) reports on results of the use of fluorescent tracers on two beaches in southern California. McArthur (1969) discusses sand movement related to beach topography near Panama City, Florida, as indicated by fluorescent tagged sand. Some of these investigations are discussed in more detail in Section IV.

2. Scope and Objectives

The RIST Study is a multiagency program directed by CERC to develop techniques and technology to utilize radioactive-tracer methods for research into sand movement and littoral processes. Detailed discussion of the scope and objectives of the overall plan were presented previously (Duane and Judge, 1969). Within the comprehensive framework of the program, the scope and objectives of these recent studies at Surf, California (Figure 1), follow:

(a) Compare patterns of sediment movement observed in radioactive sand tracer tests in the Shore Processes Test Basin (SPTB), (Taney, 1963; Duane and Judge, 1969) with patterns observed on a natural sand beach;

(b) Observe nearly synoptical patterns of sediment movement on the beach face, in the inshore and offshore zones;

(c) Compare results obtained using sand tagged with xenon-133 with those obtained using sand tagged with gold 198-199;

(d) Field test the upgraded data acquisition system; and

(e) Obtain a comparison of littoral transport under different wave conditions by conducting tests during different seasons.

To obtain initial data for the program objectives, two experiments were conducted during the fall of 1968. The first series used sand tagged with xenon-133 placed at two different times as a simulated line source extending from the beach face through the surf zone. This series of injections and subsequent tracing operations were from 25 to 29 September 1968. The second series was conducted using sand tagged with gold 198-199. To replicate the preceding xenon experiments, gold-tagged sand was also placed as a simulated line source extending from the beach face through the surf zone. Injection was made on 4 and 5 October 1968, and dispersion monitored through 9 October 1968.

During February 1969, another field test using gold 198-199 was conducted at Surf. Two simultaneous line injections were made extending from -6 to -14 feet mean lower low water and -21 to -27 feet mean lower low water. Equipment problems and high waves precluded offshore operations; tracing was confined to the beach.

This paper will describe operations and procedures used, and give a preliminary analysis of the results of the experiments.

Section II. ISOTOPES, TAGGING TECHNIQUES, AND INSTRUMENTS

1. Isotopes and Tagging Techniques

Two isotopes were used in this series of tests - xenon-133 with a half-life of 5 days and a mix of gold 198-199 with a half-life of about 3 days.

Radioactive xenon is injected into the quartz grain in a process like that of kryptonation described by Chleck, et al., (1963). In essence, the process involves heating carbonate-free quartz sand to approximately 900 degrees centigrade in an atmosphere of xenon-133, then cooling rapidly with liquid nitrogen. Labeling is a function of the mass of the particle and does not affect the hydraulic characteristics of the grain. Xenonation has been described in detail by Acree, et al., (1969).

Isotopes of gold were used in numerous sediment tracing programs (Krone, 1960; Cummins, 1964; Ingram, et al., 1965; and Hart, 1969). However, the tagging procedures have not been explained in detail. As part of one of the RIST objectives - the search for isotopes and tagging techniques suitable for sand tracing - the Oak Ridge National Laboratory (ORNL) initiated a study of existing gold-tagging techniques, and explored possible improvements. As a result of this research, a new tagging technique was developed (Stephens, et al., 1968) and utilized in RIST programs. The new technique involves pretreating carbonate-free quartz sand with a solution of p-isopropylbenzaldehyde-ethanol. After washing and drying, the sand is treated with a solution of gold chloride containing the gold isotopes 198 and 199. After decanting excess solution, the sand is cured by heating to 1,000 degrees centigrade. Leaching and abrasion tests show insignificant loss and an inclusive process efficiency of 90 percent.

Because this new ORNL technique labels the surface, two drawbacks were possible. One was inhomogeneous tagging on a mass basis because of the wide range of surface areas present in natural sands consisting of a range of particle sizes. A second was the possible effect on hydraulic characteristics of the grains. Stephens, et al., (1969) found that mass labeling could be approximated by fractionating the sand prior to tagging, and then labeling each fraction with the requisite proportion of total sample activity of gold 198-199. While their data indicate some differences in activity (counts per milligram) among the size classes, counts reported from all size classes have no significant statistical difference.

In the samples so far tested, the sand grains are slightly modified by tagging. In both xenonated and gold-tagged sand a color change is noticeable.

The untagged sand, after being leached in hydrocholoric acid, was medium grained ($\bar{X}_\phi$ = 1.7; .31 mm), was largely quartz with accessories of feldspars, metamorphic rock fragments, and heavy minerals; and was light gray in color (Munsell color code 2.5 Y 7/2 or 10 YR 7/2).

Xenonated sand was medium grained ($\bar{X}_\phi$ = 1.6; .33 mm), color was gray (7.5 YR 6/0). No noticeable change in grain morphology occurred although some agglomeration was noted, and was attributed to fusion of some grains in contact with the heating elements of the xenonation furnace during labeling.

The gold-tagged sand has a weak red color (2.5 YR 5/2), and although after tagging it still lies in the medium grain class ($\bar{X}_\phi$ = 1.97; 25 mm), it is shifted to the extreme fine end of the class and the number of size classes (variance) is narrowed (Figure 2). Some agglomeration of the gold-tagged sand occurred due to accidental overheating during the curing.

Differences between size characteristics of the gold-labeled and unlabeled sand are more difficult to explain than the small amount of agglomeration, and size analysis of gold-tagged sediments used in subsequent studies continues. Reproducibility in the size gradation process is much better than the differences apparent in Figure 2, and is therefore not considered as a cause for the deviations. As the size characteristics of the actual gold-tagged sand were within the range of characteristics of the sand at the test site, it is judged that no deleterious effects were thus introduced into the experiment. No detectable difference in specific gravity (2.65) of the sand occurred as as a result of the gold tagging;none was anticipated because only a few milligrams of metallic gold are used in tagging a liter (about 1,500 grams) of sand.

2. Injection Devices

As an improvement upon previously used emplacement techniques, water-soluble plastic bags were utilized. Available in different thicknesses and hot-water and cold-water types, this polyvinyl alcohol material has proved to be very useful. The cold-water variety is used and dissolves in 20 to 30 seconds in the limited temperature range tested (19-21 degrees centigrade). The ORNL packages tagged sand which arrives at the site ready for use. Prepackaging greatly facilitates field-site handling, and makes safety considerations simpler. Xenonated sand is packed in 1-liter quantities which are handled easily with long-handled tongs.

Gold-tagged sand, packaged in small packets of approximately 15 grams, is placed in a slotted rod fitted inside a shielded cylinder (Figure 3).

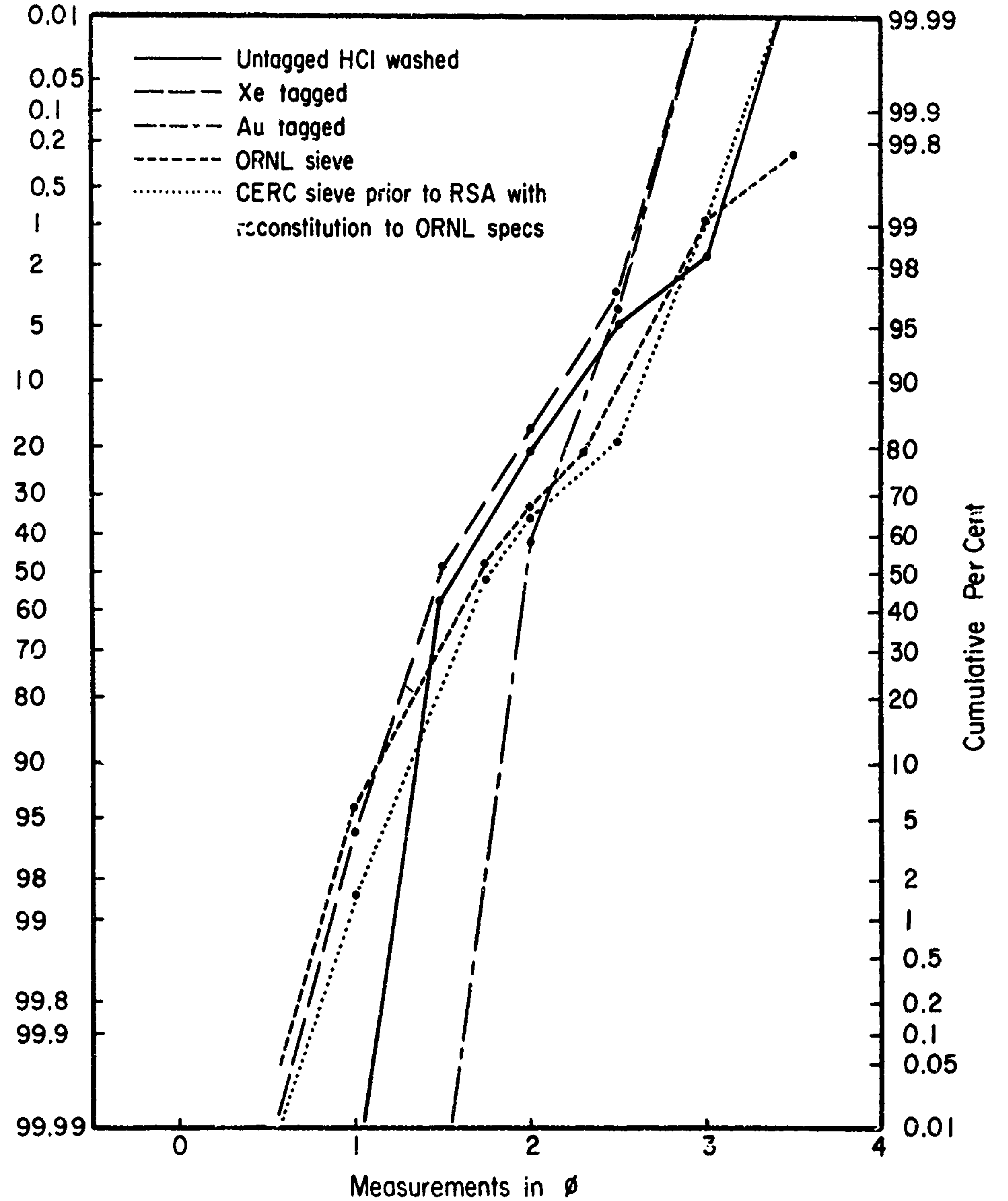


Figure 2. Cumulative size frequency curves. Three curves depicting size distribution of sand used in the reported experiments. Analysis by rapid sediment analyzer. (RSA)

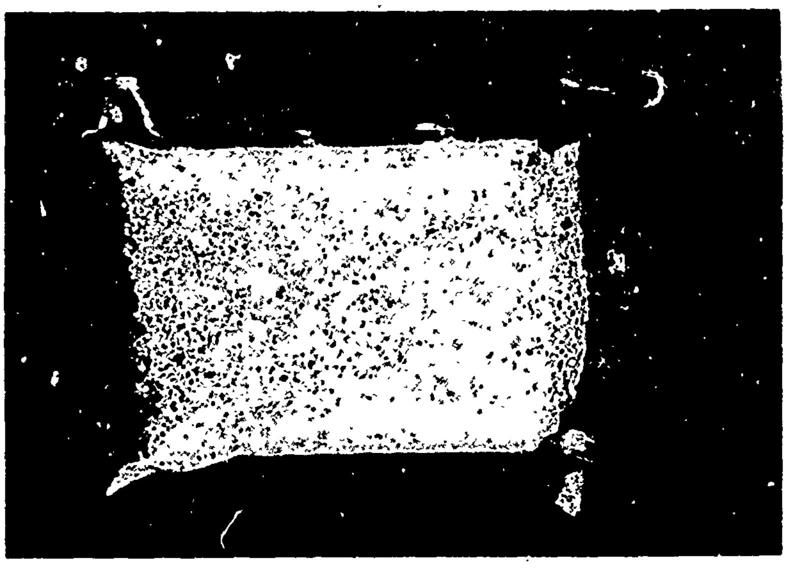


Figure 3. Packet of gold-tagged sand. When the water soluble packaging material dissolves (approximately 30 seconds) the tagged sand is free to move as individual particles responding to waves and currents.

Based on experimental results of Pirie (1965), who studied the settling rates of granule- and pebble-sized particles (2 to 64 millimeters), the packets containing the gold-tagged sand would have a settling velocity of approximately 25 centimeters per second. At this rate the packets would reach the ocean bottom in water depths up to about 25 feet before dissolving and releasing the sand to move under the influence of ambient forces on the bottom. Nevertheless, to ensure more rapid settling, the packets were weighted with several lead pellets. Also, dissolving time can be lengthened by using thicker plastic bags.

The use of sand tagged with gold, which has a higher energy gamma photon than xenon, required design of another injection device by ORNL to effect safe and efficient handling. The dispensing device described by ORNL (Case, et al., in preparation) is shown in Figure 4, rigged for operation just prior to injecting the sand. The same container, with different end plates, is used to ship the tagged sand by common carrier from Oak Ridge to the study site.

3. Detector and Onboard Data Collection System

No significant changes have been made to the towed ball-like detector vehicle (Figure 5) as previously described (Acree, et al., 1969;

Figure 4. Tagged sand carrier-dispenser installed on stern of LARC XV. Slotted trays containing 12 packets of sand lie in the shielded cylinder "A"; push rods by which the three trays are extruded are installed at the left, "B", and on the right side of the cylinder is the chute "C" into which the packets fall and slide into the ocean.

Figure 5. Amphibious LARC XV towing radiation detector vehicle entering surf. The ball-like device is connected to the LARC and the data acquisition system by means of electro-mechanical cable.

Duane and Judge, 1969), and towed behind the LARC XV amphibious vehicle which also carries the onboard data collection system. Sensitivity of the detector system, comprised of four 2- by 2-inch cesium iodide crystals, is 1 microcurie per square foot. The detector array can examine a zone about 2 feet wide along the length of the track.

The data acquisition system was modified slightly and now includes electronic circuitry for collecting two channels of radiation data and water depth (Figure 6). A high-speed, paper-tape punch was added to permit accumulation and punching of data on a 1-second basis. However, normal operational mode was at 2-second intervals, i.e., every 2 seconds the operating data channels are interrogated and read into the real-time data display and punch paper tape storage for later data handling and analysis. The system development and modifications were accomplished by the participating ORNL personnel and are detailed in reports by Acree, et al. (1969) and Case, et al. (in preparation).

The mix of gold 198-199 provides three gamma photon maxima: 80 kilo electron volts and 0.4 million electron volts for gold 198, and 0.2 million electron volts for gold 199. Discriminator settings are selected so that radiation Channel 1 sees the photon energy range from 80 kilo electron volts to 0.6 million electron volts, and Channel 2 is focused on the 80 kilo electron volts peak.

4. Computer Program

Radiation measurements are made continuously as the mobile detector is towed along a beach, through the surf zone, or along the offshore bottom. Interpretation of the detected radioactivity, in terms of speed and direction, and ultimately in volume of sand movement, depends in large measure on making maps based on the collation and manipulation of data pertaining to position, observed radiation, and time.

Individual surveys generally last from 1,000 to 6,000 seconds (about 16 to 100 minutes). As data from seven channels are accumulated every 2 seconds during the course of field surveys, as many as 21,000 bits of information may be collected. The only means of handling the data is by a computer. The basic CERC program, RAPLOT, which is written for a UNIVAC 1108, 64,000 memory computer, has undergone several modifications to refine the data processing procedures and to provide more complete and useful printed and graphic output. Details of the RAPLOT II program and information of continued direction of program modification (RADCON) are presented by Turner (1970). An example of printed output is shown in Figure 7. Graphic output consists of maps drawn on an incremental plotter (Benson-Lehner Model 305) driven by RAPLOT II-generated data. These working maps are the basis for those in Section III of this report. Work to improve data handling and analysis continues at CERC, and at ORNL.

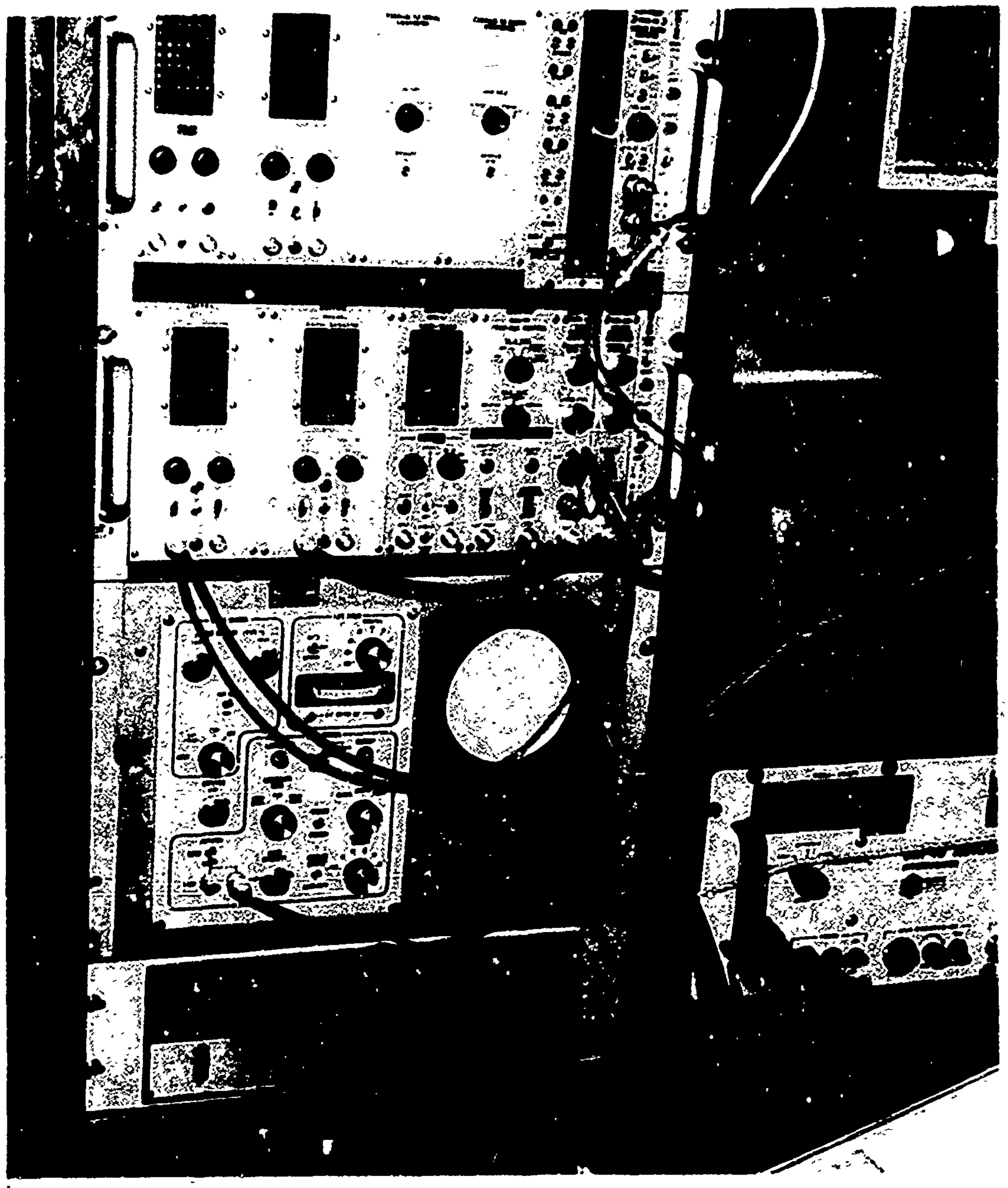


Figure 6. Onboard data acquisition system. Individual signals from the 4 scintillation detectors in the detector vehicle are fed through cables to a mixer in the instrument bank. A differential discriminator sorts the proper signals and feeds them to a multichannel analyzer (center bank). By means of a programmed interrogator (upper two banks), time and line sequence data are coordinated with the radiation data and read into the data display in real time and simultaneously onto punched paper tape. Navigation data is supplied from the Cubic Autotape interrogator (right).

SURF 600 FT S R-150 O/S RADIATION SURVEY AU-198 10/05/1968 1

LINE	TIME SEC	DISTANCE TO BEACON 1	DISTANCE TO BEACON 2	RADIATION COUNT RAD1	RADIATION COUNT RAD2	BOAT COORDINATES N	BOAT COORDINATES E	BALL COORDINATES N	BALL COORDINATES E	CORRECTED RADIATION RAD1	CORRECTED RADIATION RAD2
100	202.	1874.6	218.3	507.	412.	445503.	1217539.	445497.	1217626.	16.	14.
101	204.	1872.9	220.2	417.	336.	445508.	1217534.	445498.	1217620.	-40.	-33.
102	206.	1871.7	222.6	453.	375.	445512.	1217527.	445499.	1217612.	-18.	-9.
103	208.	1873.1	223.7	512.	401.	445507.	1217522.	445499.	1217608.	19.	7.
104	210.	1870.9	224.4	782.	643.	445514.	1217521.	445500.	1217606.	186.	156.
105	212.	1871.7	225.5	895.	757.	445511.	1217517.	445500.	1217603.	256.	227.
106	214.	1869.1	227.3	852.	695.	445520.	1217513.	445501.	1217597.	229.	189.
107	216.	1866.9	229.9	772.	636.	445520.	1217504.	445503.	1217589.	180.	152.
108	218.	1867.6	232.8	991.	830.	445524.	1217495.	445505.	1217579.	315.	272.
109	220.	1867.3	234.0	610.	515.	445525.	1217491.	445506.	1217576.	80.	77.
110	222.	1864.2	235.9	670.	554.	445535.	1217487.	445508.	1217569.	117.	101.
111	224.	1865.1	237.5	1054.	829.	445531.	1217481.	445509.	1217565.	354.	271.
112	226.	1862.8	238.7	699.	569.	445539.	1217479.	445511.	1217560.	135.	111.
113	228.	1863.3	241.5	1532.	1279.	445537.	1217469.	445513.	1217552.	650.	550.
114	230.	1862.3	243.8	5371.	4316.	445540.	1217462.	445515.	1217545.	3024.	2428.
115	232.	1861.7	245.0	25640.	20514.	445542.	1217455.	445517.	1217538.	15559.	12445.
116	234.	1860.7	247.5	87273.	64306.	445545.	1217450.	445519.	1217533.	53675.	39528.
117	236.	1859.4	247.8	96964.	68937.	445549.	1217450.	445519.	1217532.	59668.	42392.
118	238.	1859.9	249.6	89936.	66694.	445547.	1217444.	445521.	1217526.	55322.	41129.
119	240.	1856.4	251.9	106373.	71646.	445558.	1217439.	445524.	1217518.	65488.	44068.
120	242.	1858.1	254.7	111948.	65506.	445552.	1217428.	445527.	1217510.	69936.	40271.
121	244.	1855.1	256.2	110469.	62194.	445562.	1217425.	445529.	1217505.	67985.	38223.
122	246.	1855.9	257.2	112288.	66458.	445559.	1217421.	445530.	1217503.	69147.	40880.
123	248.	1855.0	258.6	108223.	65064.	445562.	1217417.	445532.	1217498.	66633.	39998.
124	250.	1854.6	260.5	110980.	66978.	445563.	1217411.	445534.	1217492.	68339.	41182.
125	252.	1852.7	263.1	83602.	62203.	445569.	1217404.	445537.	1217484.	51407.	38229.
126	254.	1853.3	264.6	103150.	71661.	445567.	1217398.	445539.	1217480.	63497.	44079.
127	255.	1851.3	266.8	91411.	65596.	445574.	1217392.	445541.	1217473.	56237.	40328.
128	258.	1851.7	268.8	72941.	55957.	445572.	1217385.	445544.	1217467.	44814.	34367.
129	260.	1851.3	271.0	80645.	60915.	445573.	1217378.	445546.	1217460.	49579.	37433.
130	262.	1850.4	272.7	64974.	50379.	445576.	1217373.	445548.	1217455.	39887.	30917.
131	264.	1849.3	274.4	73980.	56493.	445580.	1217368.	445550.	1217449.	45458.	34659.
132	266.	1848.7	276.9	75302.	57286.	445581.	1217360.	445552.	1217441.	46275.	35189.
133	268.	1848.5	278.7	32945.	26779.	445582.	1217354.	445554.	1217436.	20078.	16321.
134	270.	1846.2	281.0	68962.	53878.	445589.	1217348.	445557.	1217429.	42355.	33082.
135	272.	1847.1	284.0	64947.	51155.	445586.	1217337.	445560.	1217420.	39872.	31398.
136	274.	1844.3	[illegible]5.1	74727.	57614.	445595.	1217336.	445562.	1217416.	45921.	35393.
137	276.	1845.9	287.3	69652.	54019.	445590.	1217327.	445564.	1217409.	42782.	33170.
138	278.	1846.0	289.3	45326.	36185.	445590.	1217320.	445566.	1217403.	27737.	22139.
139	280.	1845.4	290.8	31978.	25467.	445592.	1217316.	445567.	1217399.	19481.	15758.
140	282.	1845.3	293.2	20751.	16964.	445592.	1217308.	445569.	1217391.	12537.	10251.
141	284.	1845.8	294.8	9030.	7464.	445590.	1217302.	445570.	1217386.	5287.	4375.
142	286.	1844.2	296.5	6516.	5331.	445595.	1217297.	445572.	1217380.	3733.	3056.
143	288.	1844.3	298.[illegible]	4406.	3630.	445595.	1217290.	445573.	1217374.	2427.	2004.
144	290.	1843.5	300.3	2833.	2366.	445597.	1217284.	445575.	1217368.	1455.	1222.
145	292.	1842.3	302.4	4490.	3626.	445601.	1217274.	445577.	1217362.	2479.	2001.
146	294.	1842.8	305.4	1075.	1381.	445600.	1217268.	445579.	1217357.	738.	613.
147	296.	1842.0	308.0	849.	687.	445602.	1217260.	445581.	1217344.	227.	184.
148	298.	1840.8	309.5	621.	501.	445606.	1217256.	445583.	1217339.	86.	69.
149	300.	1839.6	311.5	914.	735.	445610.	1217250.	445585.	1217333.	268.	213.

Figure 7. Computer listing of RIST data. A typical page of data from a survey (5 Oct 1968). Distance in meters; radiation count accumulated for 2 seconds; coordinates, California Lambert System; corrected radiation, counts per second corrected for background and decay.

Section III. FIELD TESTS

1. General Program Design

Field tests conducted during September-October 1968 were designed to determine zones of maximum sediment movement (velocity) on a real beach; improve all aspects of the RIST operation over previous studies; test the modified instrumentation and new hardware; compare relative merits of utilizing sand tagged with either xenon-133 or gold 198-199; and for the first time known to the author, attempt to simultaneously trace sediment movement on the beach face, and in the inshore and offshore zones.

The beach near Surf, California, on Vandenberg Air Force Base property, was selected for the test site (Figure 8). It is a relatively straight, sandy beach, and the nearshore bottom is sandy to -30 feet mean lower low water and beyond (Figure 9). To accomplish the several objectives, replicate experiments were designed using the two isotopes. In each instance, the packets of isotopically labeled sand were dropped at 5-meter intervals along a line extending from the foreshore into the nearshore zone. Actual length of the injection line varied somewhat; this is explained later in this section.

As a backup to instrumental sensors, and wave-weather forecasts, visual observation of littoral environmental factors were obtained using the methods described by Berg (1968) and Szuwalski (1970). These observations, made at least twice daily, provided data on wind speed and direction, tide, wave and breaker characteristics, littoral current and beach slope. As a consequence of instrument sensor failures, dependence had to be placed on the visual observations and the wave and weather forecasts.

Radiation measurements are made continuously as the mobile detector system is towed along the beach, through the surf zone, or along the offshore bottom. Position of the LARC XV is determined directly by the Cubic Autotape navigation system used; position of the radiation detection vehicle is computed. The schematic diagram (Figure 10) illustrates a typical RIST survey, based upon the actual experimental operations at Surf. Data and placement of injection and isotope activity are summarized in Table I.

2. Xenon Experiments

On 25 September 1968, 36 1-liter packets of xenonated sand (specific activity 42.3 microcuries) were placed as a simulated line injection 590 feet (180 meters) long from +6 feet mean lower low water to -6 feet mean lower low water. The approximate position of the injection along the range is shown on Figure 11 which represents conditions immediately following injection. Several surveys a day were

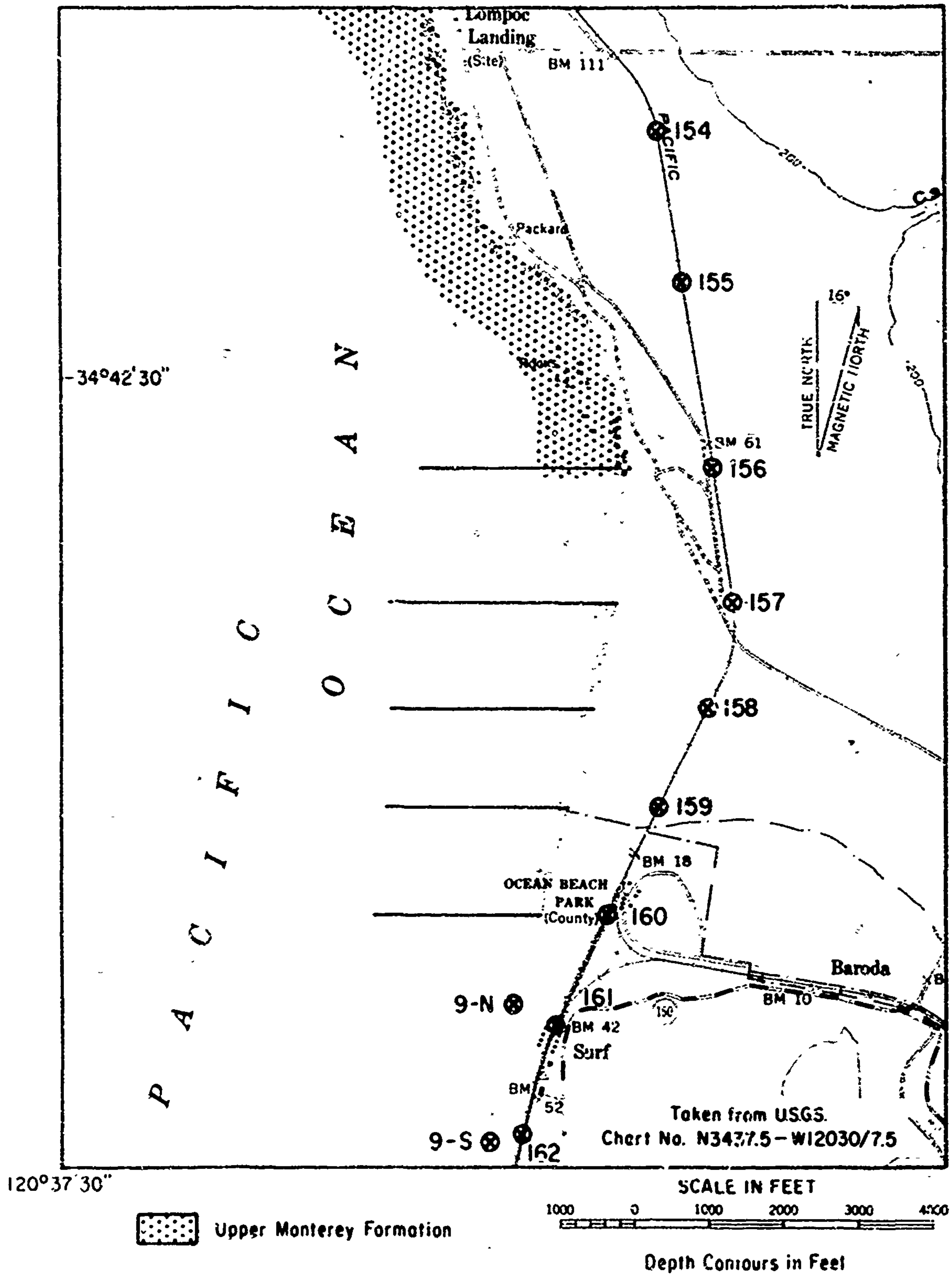


Figure 8. Detail of study area. Tracing operations were limited to area bounded by Ranges 156 and 160 and approximately the 30-foot depth contour.

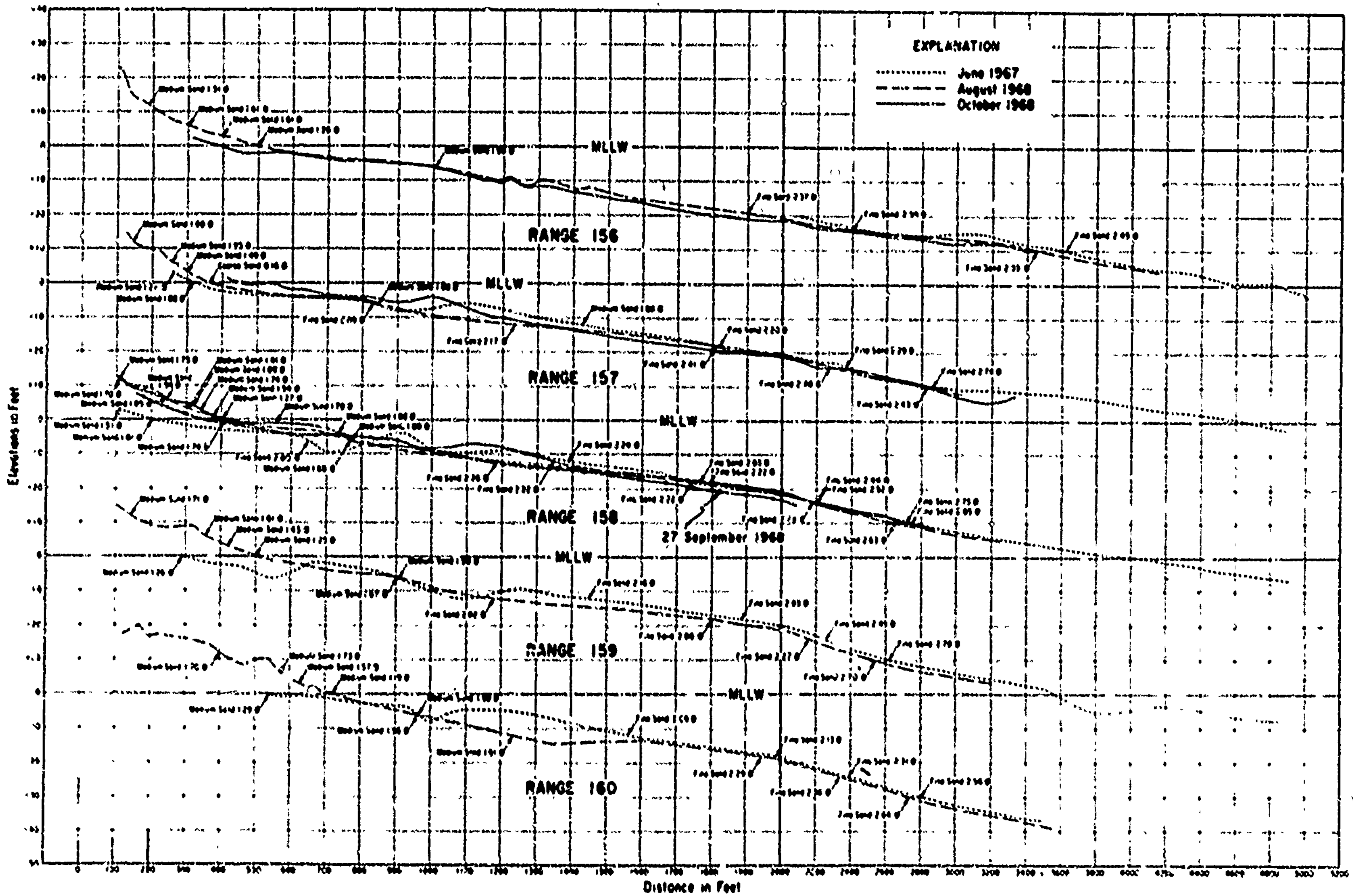


Figure 9. Profiles normal to the shore. Horizontal distances are from off-set hubs, not the main turning points. Sand characteristics are phi mean; samples collected at time of profiling.

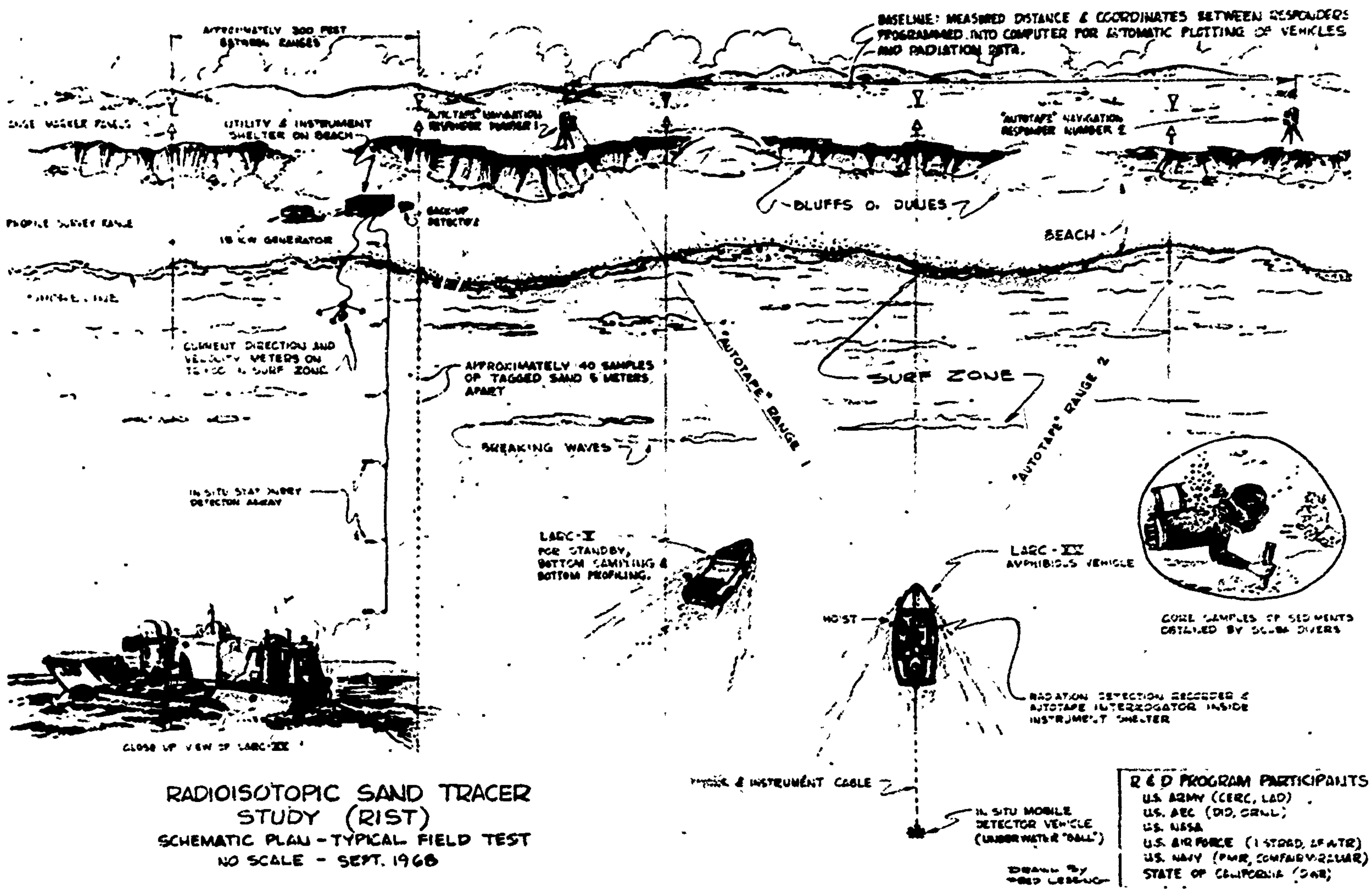


Figure 10. Schematic illustration of RIST tracing operations.

TABLE I

SUMMARY OF INJECTIONS

DATE and TIME	ISOTOPE	RADIOACTIVITY Specific (Microcuries per cubic centimeter)	RADIOACTIVITY Total (Curies)	INJECTION LINE Elevations	INJECTION LINE Length
25 September 10:45 a.m.	Xe-133	42.3	1.7	+6' to -6' MLLW	590'
28 September 11:37 a.m.	Xe-133	8.7	0.35	+6' to -8' MLLW	672'
4 October 11:13 a.m.	Au-198/199	47000	15.8	-4' to -11' MLLW	394'
5 October 11:32 a.m.	Au-198/199	22000	11.0	+5' to -6' MLLW	640'

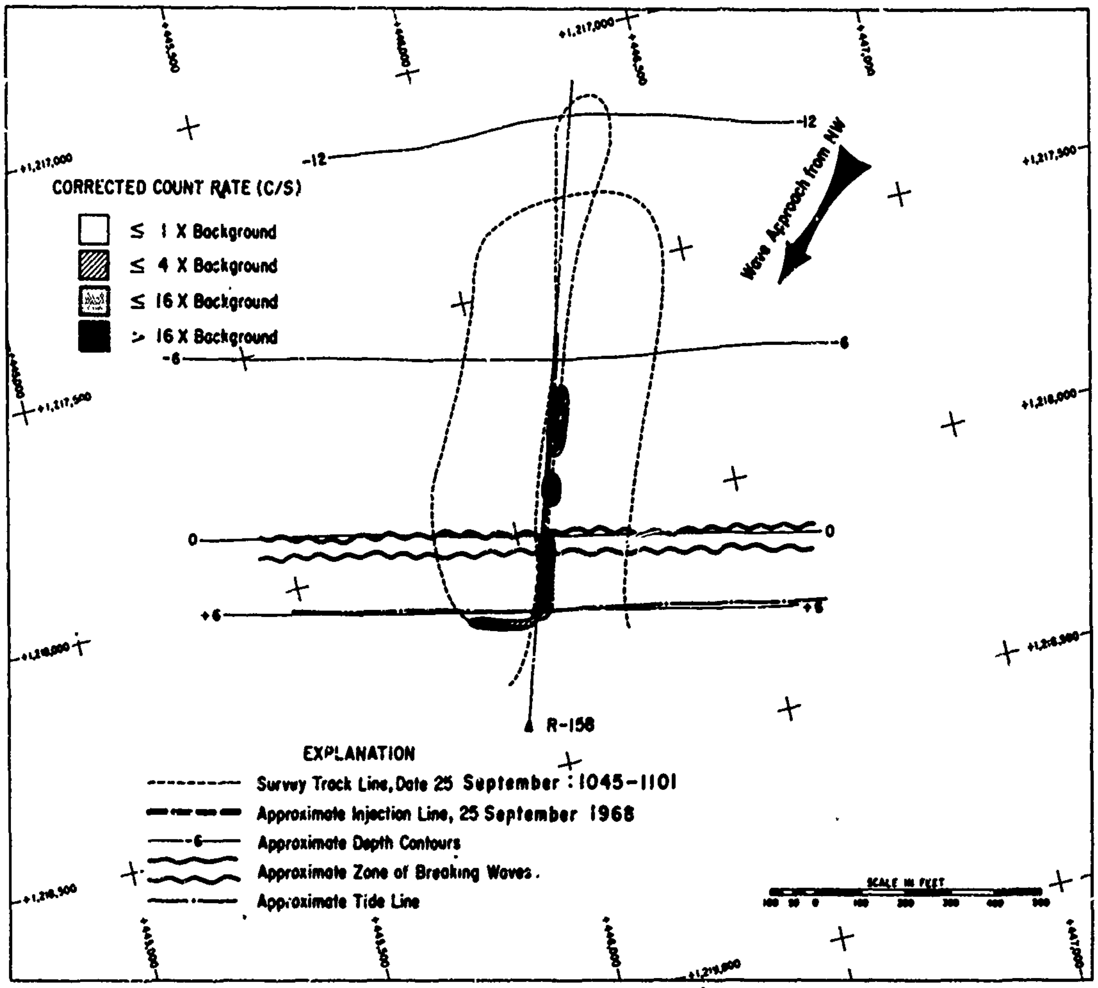


Figure 11. Pattern of xenonated sand immediately after release. The detector was operating and towed behind the LARC XV during emplacement of the sand.

made through 28 September 1968, with patterns very similar to the pattern depicted by data collected in the morning of 26 September (Figure 12). On 28 September, a second line injection was made about 1,200 feet (635 meters) south. This line was about 672 feet (205 meters) long. Surveys following the second injection never positively identified the injection, although tagged sand was still identifiable at the site of the first injection, probably because of burial. It is assumed that sand injected during the second operation was rapidly transported downcoast (south) and dispersed below detectable limits. Littoral transport is summarized in Figure 13. Sea and swell are summarized in Figure 14.

Short cores of sediment were obtained along the injection range on 25, 26, and 28 September 1968 at varying elevations, but always one sample at mean lower low water. On 28 September, cores were also obtained 50 feet (15.2 meters) north and south of the first injection line (Range 158) and along the second injection range (300 feet north of Range 159). Samples were removed from the cores at 2-inch intervals, and counts made. The energy spectrum was displayed during the counting operation to ensure that xenon was present, especially where counts were only slightly above background. Some of these data are depicted in Figure 15 which clearly indicates burial of tagged sand.

3. Results of Xenon Experiment

Patterns of sediment dispersal and burial depicted in Figures 11, 12, and 15 make conclusions concerning sediment movement tenuous, particularly since a count-rate balance is lacking. Based on the approach of Bagnold (1947) and the ambient ocean waves and currents (summarized in Figures 12 and 13), the tagged sediment was expected to move a considerable distance downcoast. But dispersal patterns indicated only slight downcoast movement. Core data indicate burial, yet intuitively, nearly total burial seems untenable. An alternative possibility is that movement of the tagged sand occurs, but in a manner whereby the particles stream off in a random pattern at a random rate. If this is the case, it is entirely possible that the streaming rate, coupled with the low specific activity level of the xenonated sand, moves particles downcoast at a rate below the level of detectability of the system.

The experiment in the CERC Shore Processes Test Basin (SPTB) in 1968 indicated that a small quantity of high specific activity xenonated sand would produce dispersal patterns similar to those of a larger quantity of low specific activity xenonated sand. Therefore, the subsequent field experiment with gold-tagged sand - analogous to the high specific activity xenon sand in the laboratory experiment - should provide some insight into the reason for the observed xenon patterns. Assuming burial of the sediment or no movement of the sediment, then the gold-tagged sand should describe the same (or closely similar) pattern as that depicted by the xenonated sand. Conversely, if movement of xenon-tagged sand

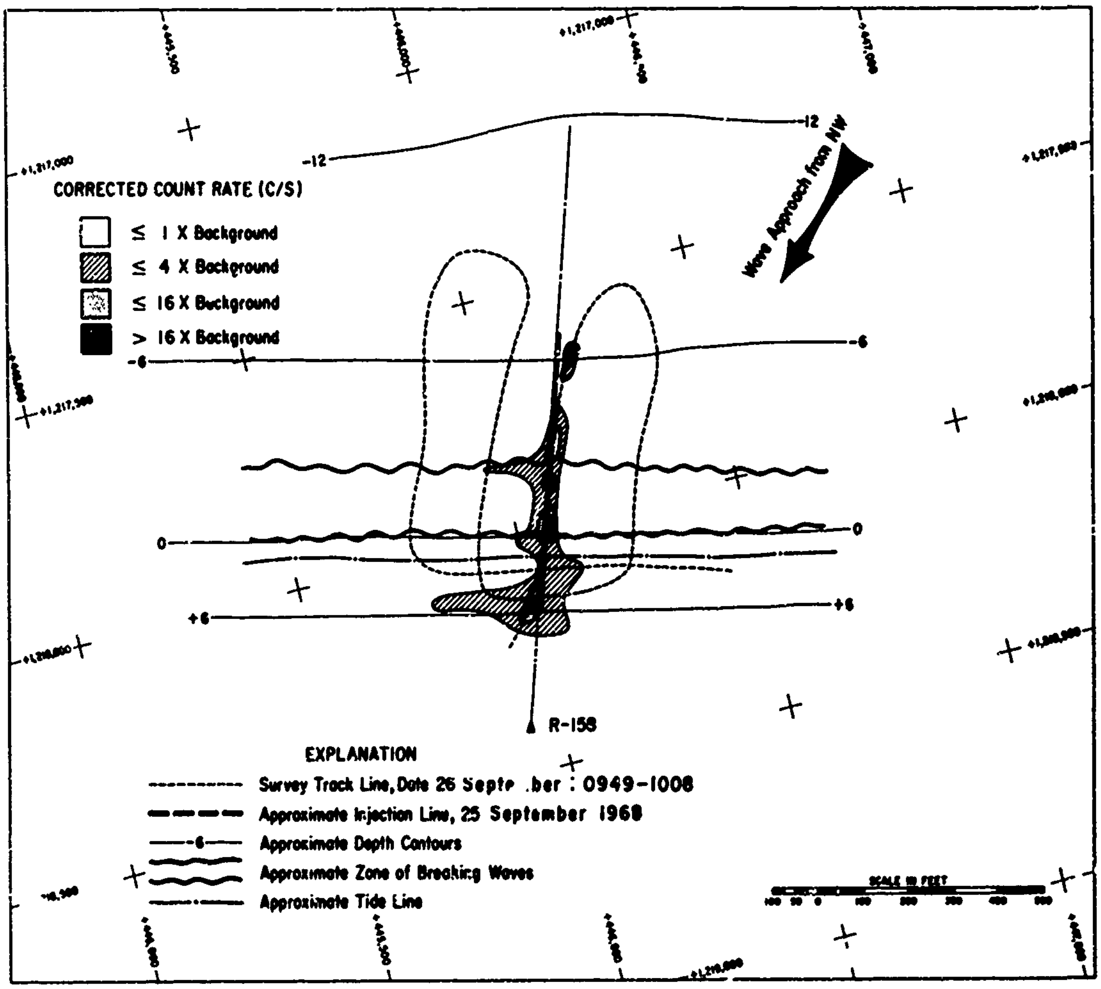


Figure 12. Pattern of xenonated sand approximately 24 hours after emplacement.

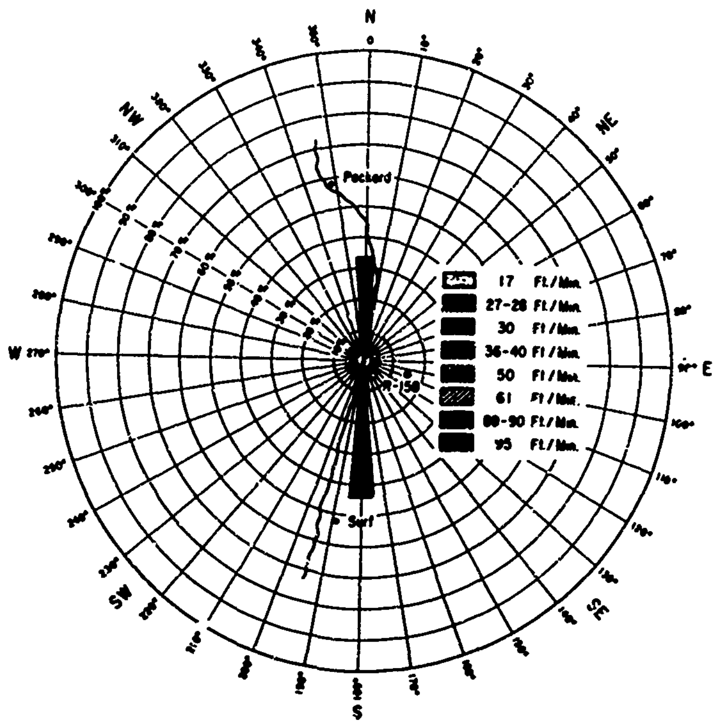
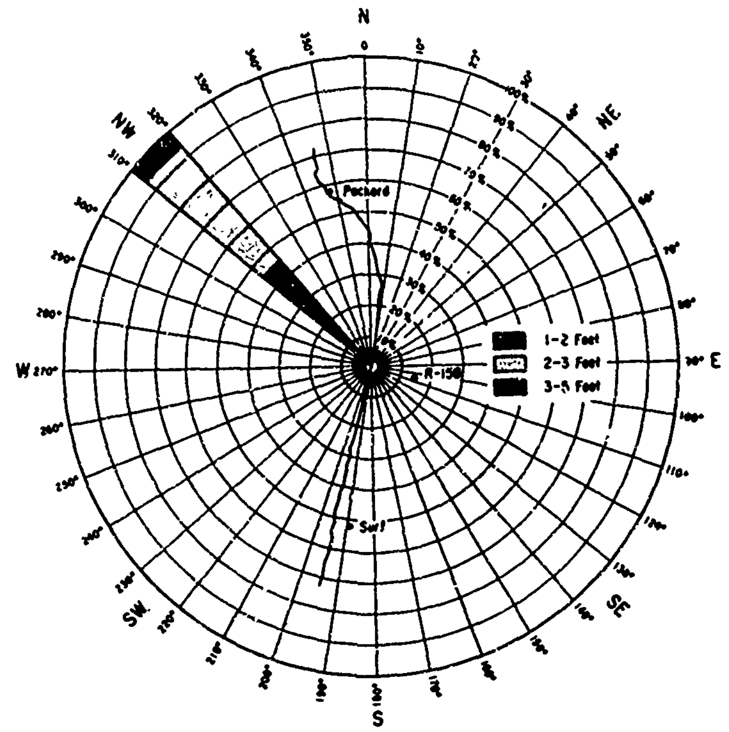
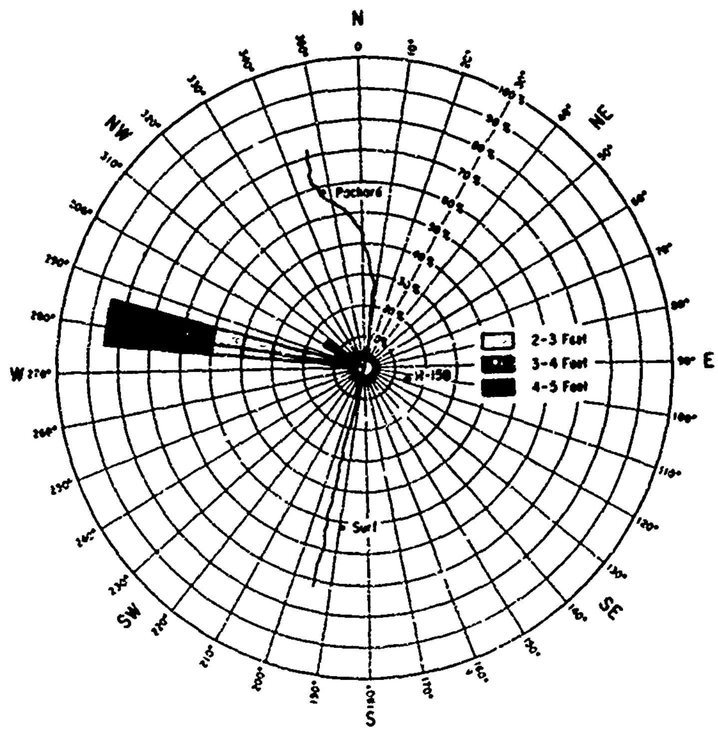


Figure 13. Littoral transport summary, xenon experiments. Measured using dye placed in the inshore zone. Figure shows velocity and direction from injection point.



Sea



Swell

Figure 14. Sea and swell summary, xenon experiments. Height in feet and direction from which the waves are advancing.

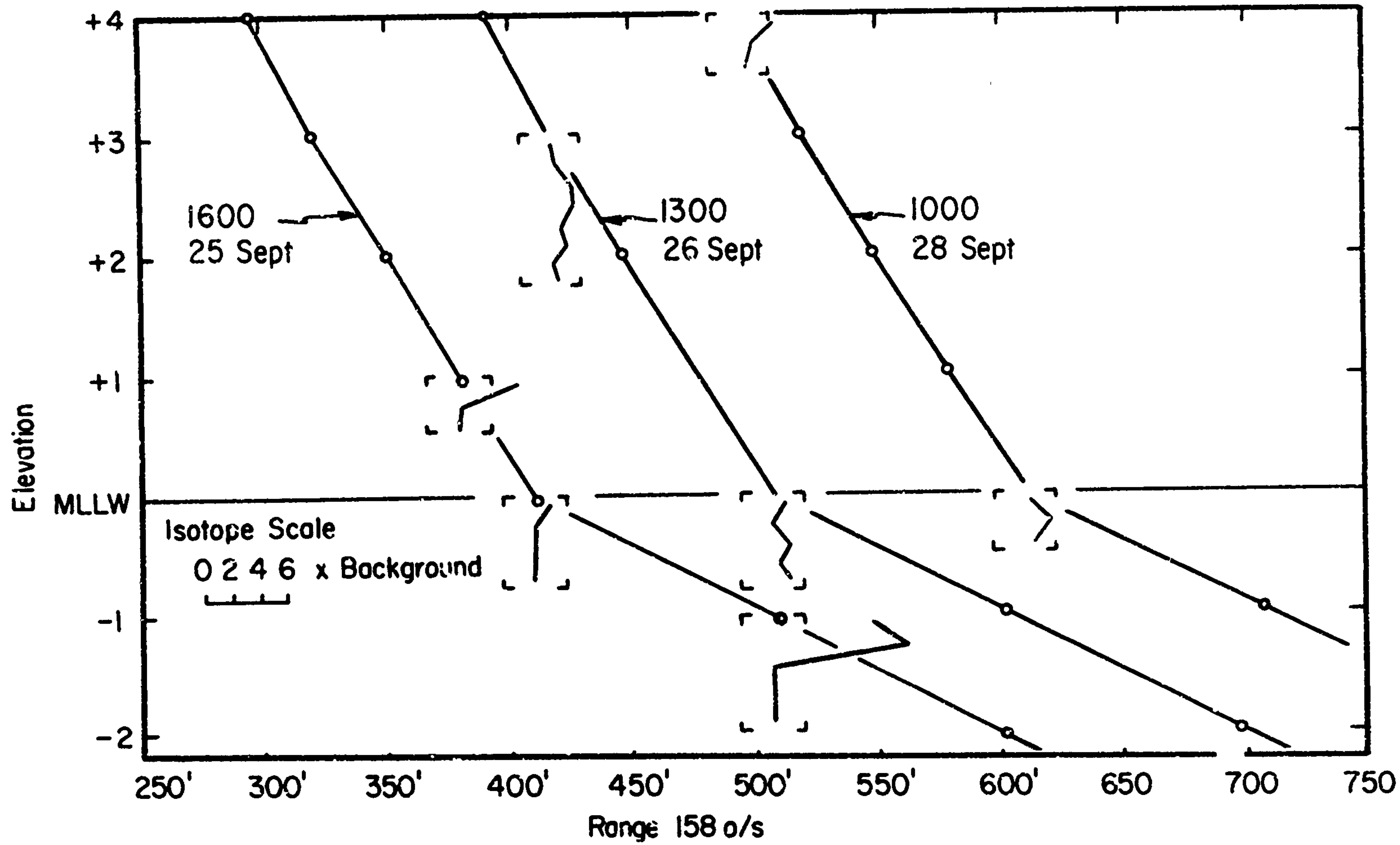


Figure 15. Location of cores along profiles 50 feet upcoast (-) and 50 feet downcoast (+) from R-158, site of xenon injection, 25 September 1968. Cores were obtained approximately 6 hours after injection of the isotope as a line source from +6 to -6 feet MLLW on R-158. Radiation counting was done at the site and in the case of low counts, xenon was verified by its energy spectrum displayed on the cathode ray tube of the multichannel analyzer in Figure 6.

occurred, but at a rate and in a manner which was below detectability level, then wide dispersal of the gold-tagged sand would be noted. Results of the experiments using the gold-tagged sand indicate the xenonated sand did move.

4. Gold Experiments

On 4 October 1968, 24 packets containing about 14 cubic centimeters of sand tagged with gold 198-199 specific activity 47 microcuries were placed as a simulated line injection 426 feet (130 meters) long from -4 feet to -11 feet mean lower low water. The track of the vessel during injection and conditions 2 hours after injection are shown in Figure 16; and 4 hours after injection in Figure 17. Dispersal of the tagged sand from one injection line 23 hours after emplacement is shown in Figure 18. An hour after that survey, a second injection of gold-tagged sand was made 600 feet upcoast. In this operation 36 packets of gold-tagged sand (specific activity 22 microcuries) were placed as a line 575 feet (175 meters) long from about +5 feet to about -6 feet mean lower low water. The precise path the LARC XV described during injection procedures is not known because of electronic problems. Due to wind and longshore drift, the actual track was some distance downcoast (south) of the planned line along Range 158 illustrated on Figure 19, which also shows the dispersion of gold-tagged sand 2 and 26 hours after the second and first gold injections, respectively. A subsequent survey on 5 October is illustrated in Figure 20. Results of the final full-scale survey of this test 4 days later are shown in Figure 21. In total, although not all surveys are illustrated here, 23 surveys of varying duration and areal extent were conducted. The information from all plots was used in drawing the maps in Figures 16 through 21. Longshore current, sea, and swell during the experiment are summarized in Figures 22 and 23.

Short cores of sediment were obtained along the injection range (R-158) at elevations from -6 feet to +6 feet mean lower low water on 5, 7, 8 and 9 October. Cores were also obtained 50 feet north and south of Range 158. No radioactivity was detected in the cores although surveys showed tagged sand to be in the area. Lack of tagged particles in the cores is judged to be due to the small diameter of the core and the relatively few tagged grains which make the probability of coring tagged or radioactive grains very small.

As a result of burial, degradation of the higher energy photons occurs with enhancement of the lower energy peaks, in this instance 80 kilo electron volts peak. Ratios of counts read in the two discriminate-radiation counting channels are a measure of burial, i.e., the larger the number the deeper the sand is buried. It is not yet possible to give significance to burial depths indicated by the ratio, although the qualitative significance is useful. Ratios of corrected count rate are computed as follows:

$$R_D = \frac{R_2}{R_1 - R_2}$$

where

R_D = burial depth ratio

R_1 = corrected count rate (c/s) in RAD Channel 1

R_2 = corrected count rate (c/s) in RAD Channel 2

R_1 and R_2 represent an average of 10 readings. On the beach face, computed ratios indicate burial with time on the injection line. Laterally along the beach face, ratios indicate sand is nearer the surface as distance from the injection line increases. Seaward of the surf zone, little lateral change in ratios was detected, although an increase in ratios occurred through time. Interpretation is that mixing to some depth has occurred, rather than stratification with an overburden of dead sand.

5. Results of Gold Experiments

A comparison of maps showing the distribution of xenon- and gold-tagged sand (Figures 11 and 12, and 16 through 21) indicates differences in areal extent and possible interpretive differences. Some differences in grain size of tagged sand was noted in a previous section of this paper. As the size characteristics were still similar to the untagged sand in the study area, no deleterious effects are judged to have occurred because of tagging techniques. Tests at ORNL (Stephens, et al., 1969) indicate their tagging techniques firmly fix the radioactive gold to the grain surface. The maps are therefore judged to represent dispersion of sand grains and not the dispersion of gold abraded or leached from the surface of sand grains.

Differences in ocean conditions during the xenon and gold experiments might be the cause of the different patterns of movement suggested by the maps. However, during the first days of the gold experiment, sea, swell, and longshore currents were closely similar to those during the xenon experiment. During 6, 7, and 8 October, wind and swell were considerably higher than any conditions encountered during the earlier xenon tests.

Gamma photons emitted by gold are much greater than xenon in energy (0.4 million electron volts versus 0.08 million electron volts). Therefore, they are more easily detected, even in smaller grain concentrations, than xenon-tagged sand. It is the consensus of the field-program participants that the data used in compiling maps depicting movement of gold-tagged sand are real, and that for purposes of working in the ocean environment on a large scale, gold-tagged sand yields better information than sand labeled with xenon using present tagging techniques.

An experiment in the CERC SPTB to study littoral drift indicated rapid alongshore movement at the landward edge of the breaker zone, and

Text resumes on page 34

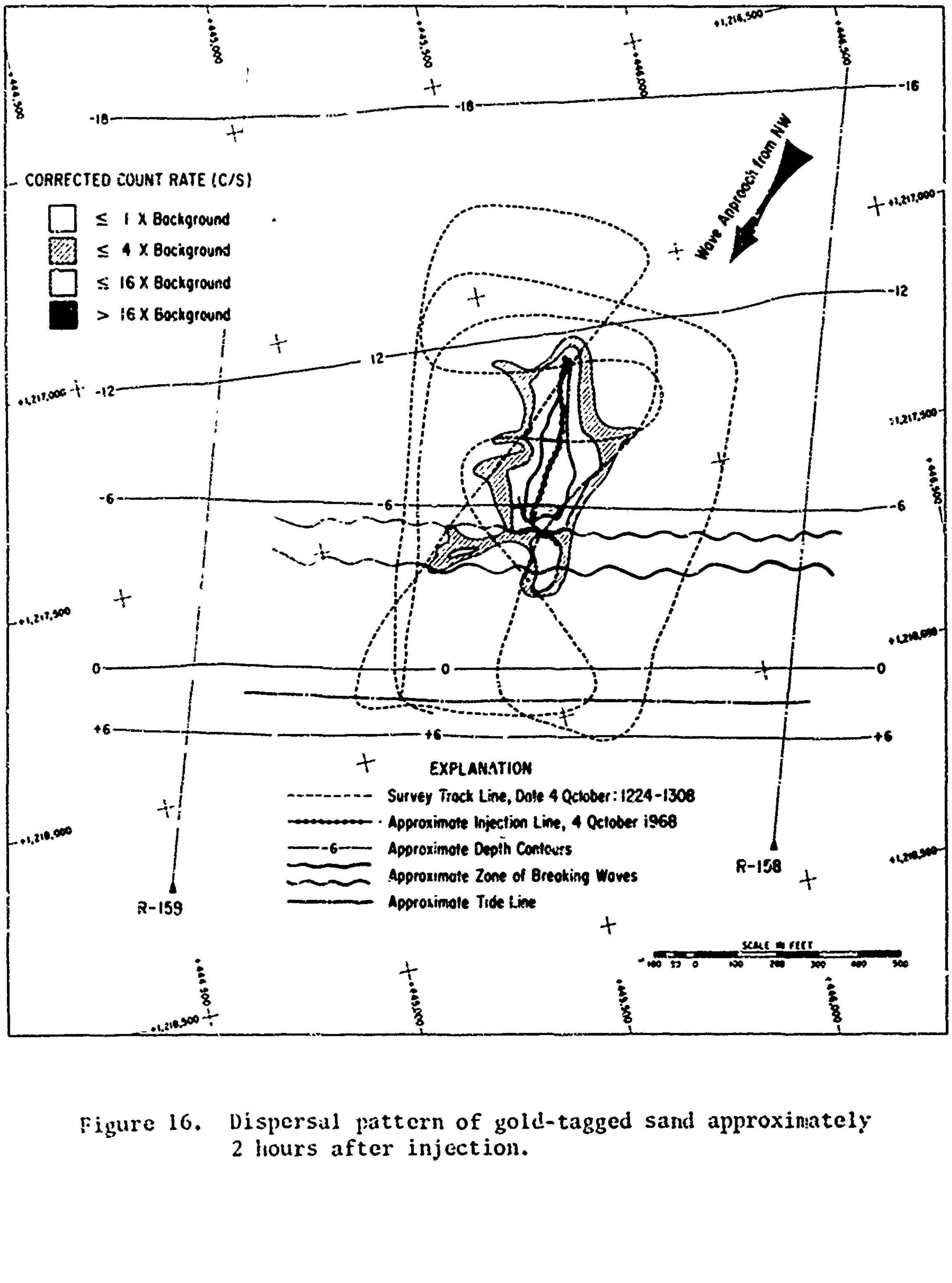


Figure 16. Dispersal pattern of gold-tagged sand approximately 2 hours after injection.

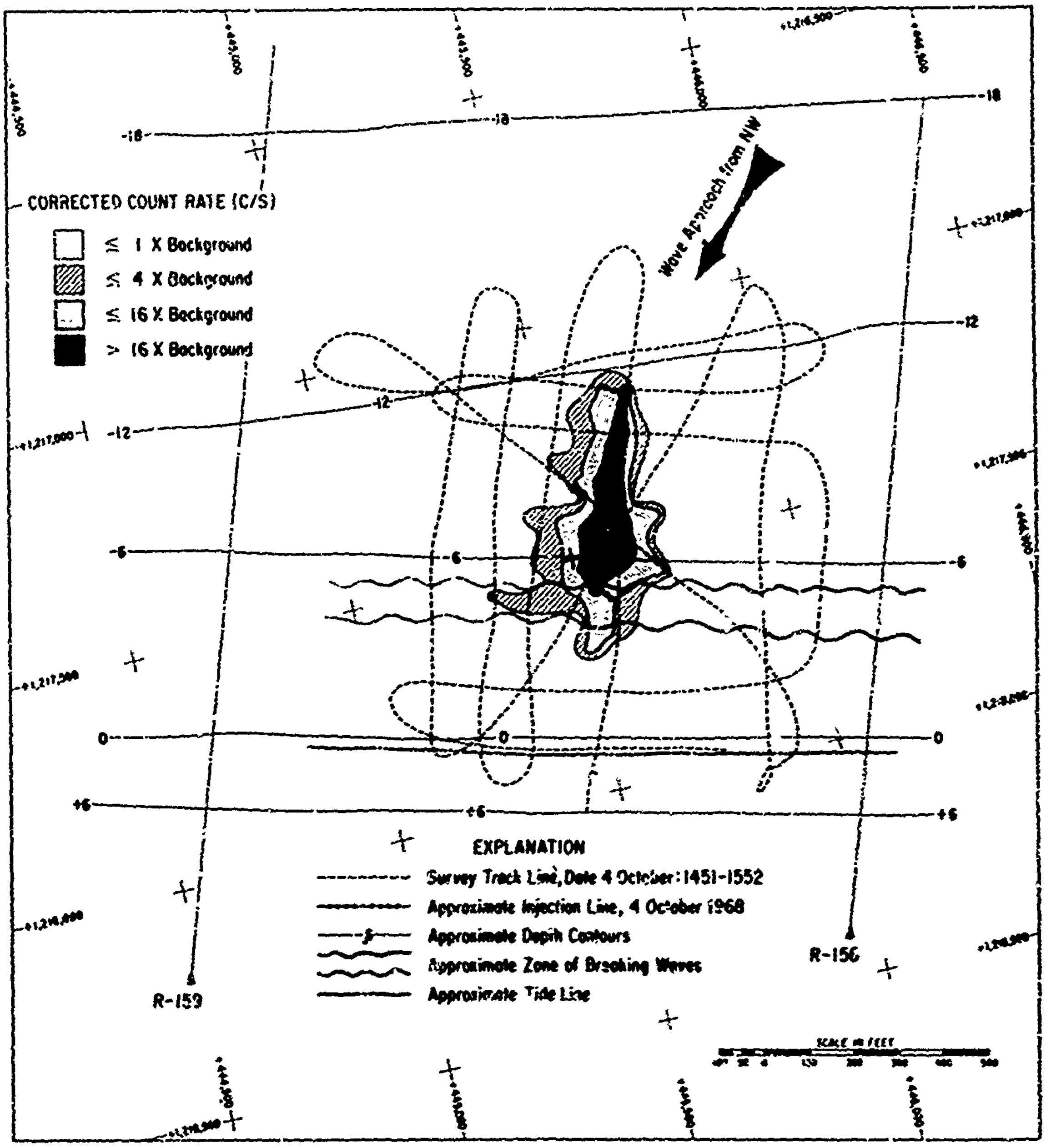


Figure 17. Dispersal pattern of gold-tagged sand approximately 4 hours after injection.

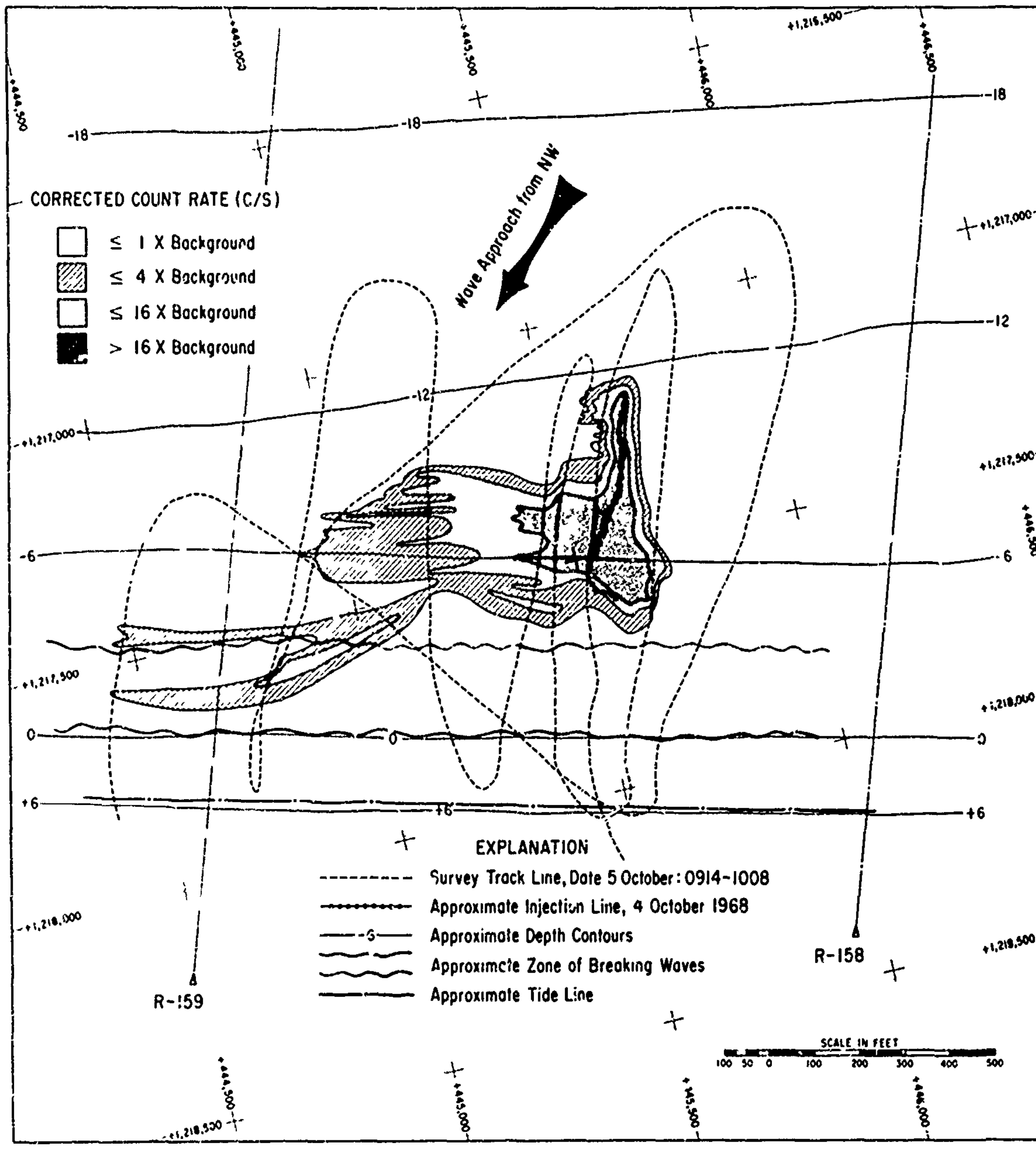


Figure 18. Dispersal pattern of gold-tagged sand approximately 23 hours after injection. Note the rather abrupt upcoast (north) truncation of the pattern and the minor movement shoreward.

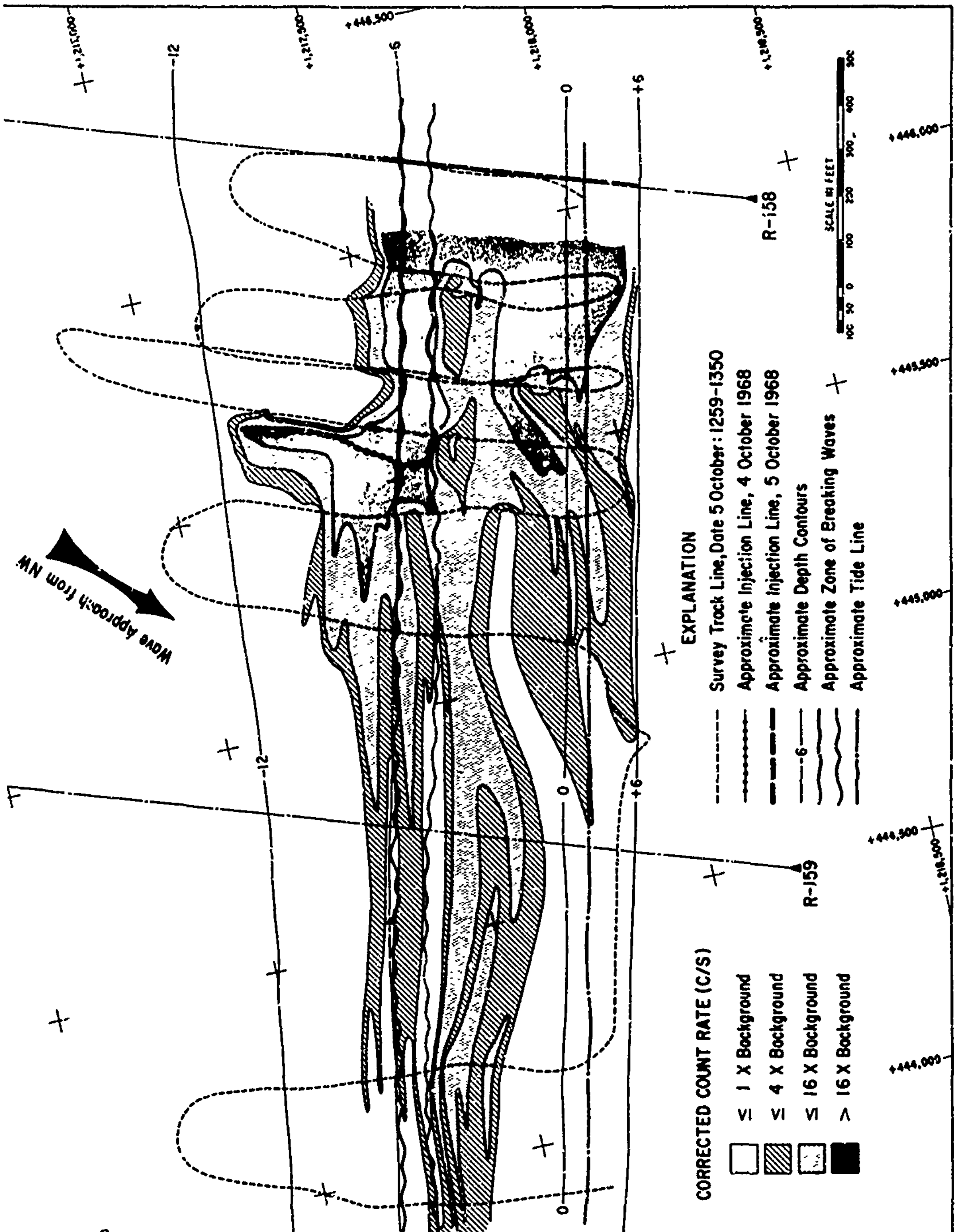


Figure 19. Dispersal pattern of gold-tagged sand 2 hours after the injection of 5 October from approximately +6 feet to -6 feet MLLW 600 feet upcoast of the earlier gold injection. Note very rapid downcoast movement of tagged sand just inshore of the breaker zone.

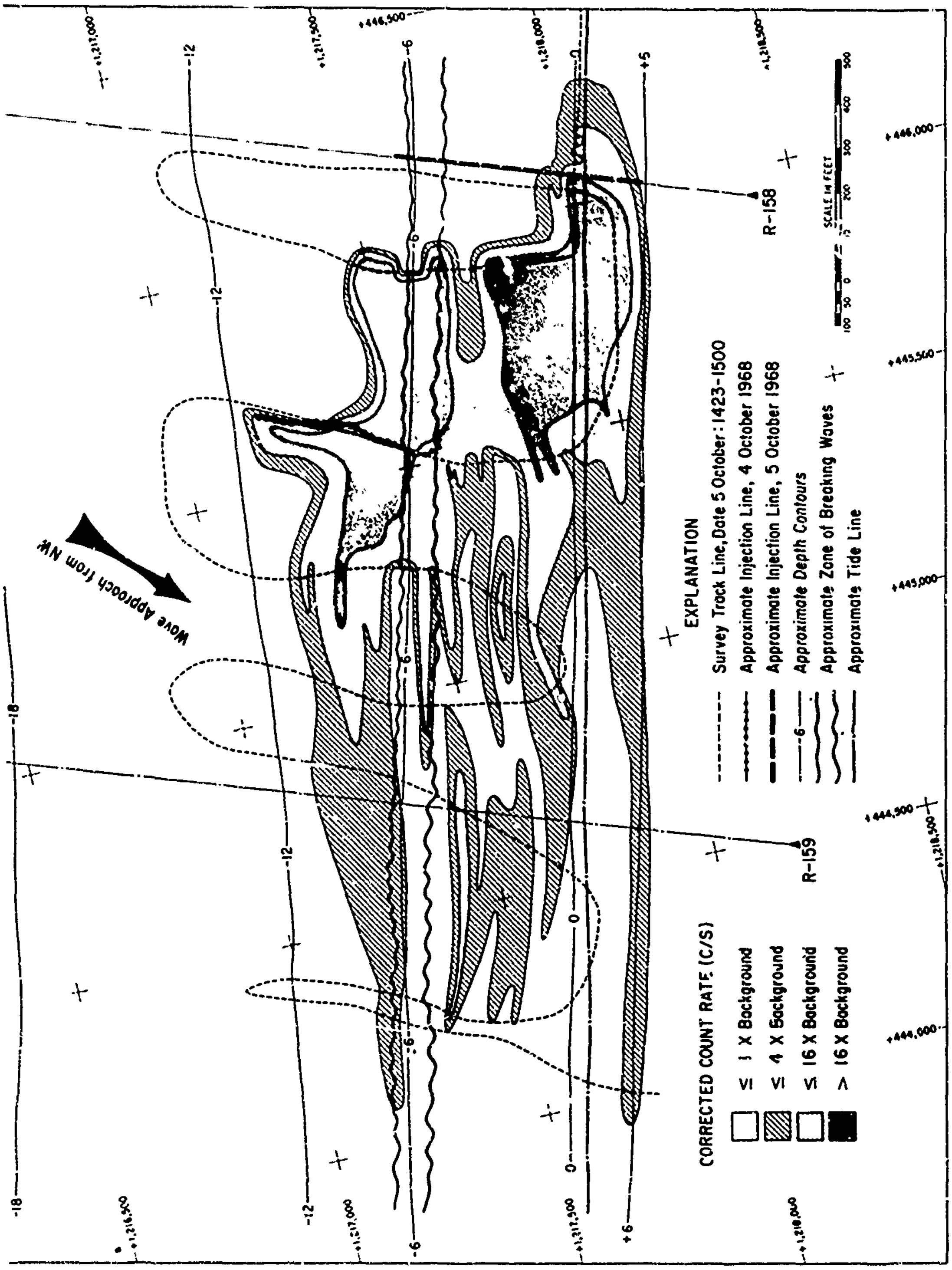


Figure 20. Dispersal pattern of gold-tagged sand observed approximately 1 hour after the pattern depicted in Figure 19.

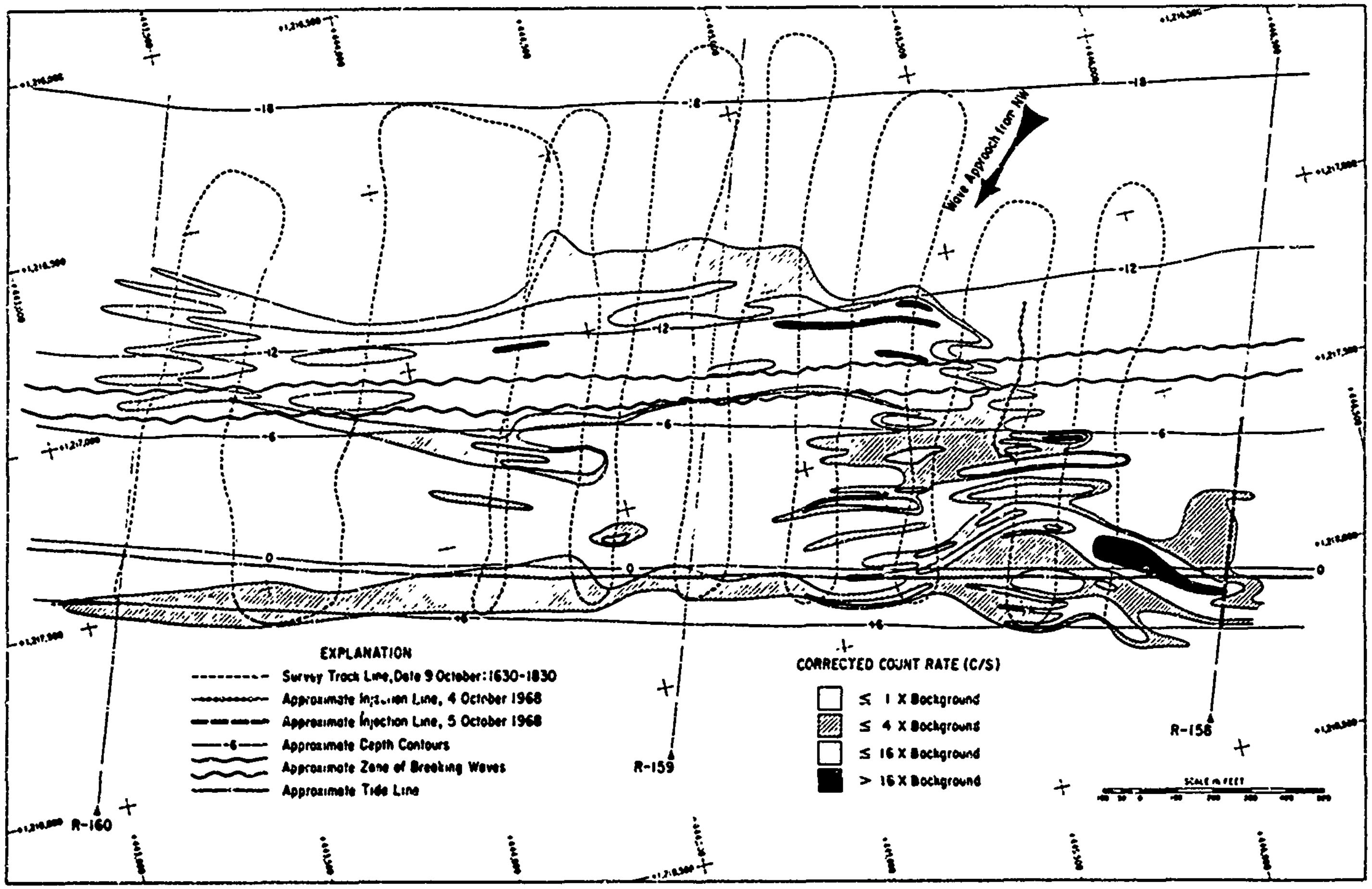


Figure 21. Pattern of gold-tagged sand observed four days subsequent to the survey depicted in Figure 20.

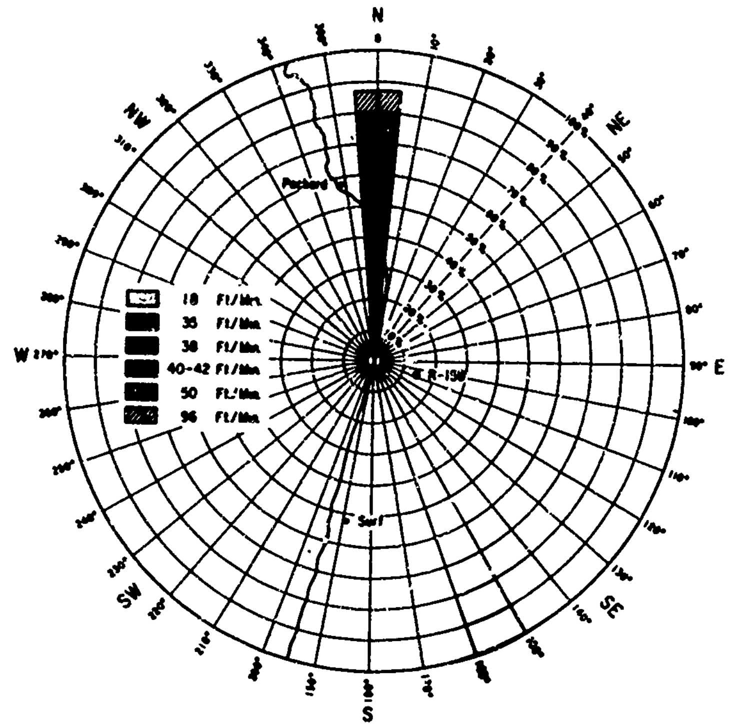
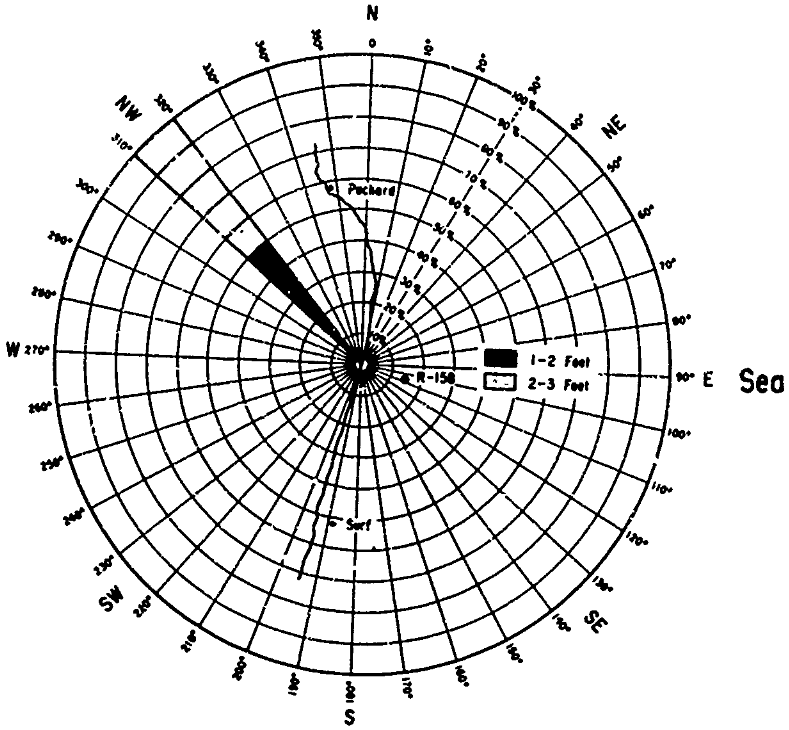


Figure 22. Littoral drift summary, gold experiment. Measured using dye placed in the inshore zone, data is velocity and direction from injection.



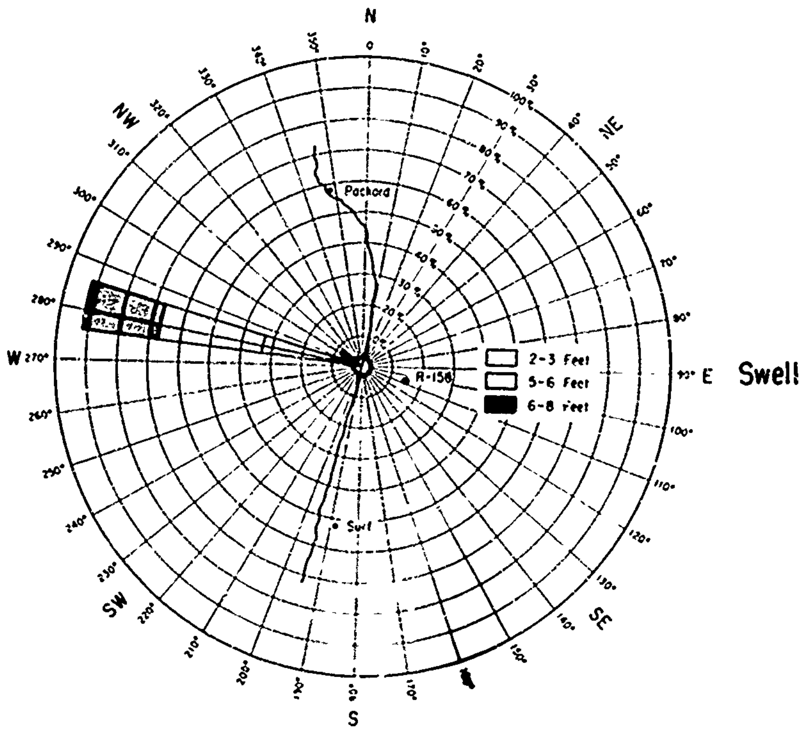


Figure 23. Sea and swell summary, gold experiments. Height in feet and direction from which the wave is approaching.

for a short distance seaward of the breaker zone (Taney, 1963). In a 2-dimensional sense, several aspects of that model are analogous to the field data. Core data, obtained at Surf, California, indicate far deeper burial (maximum 1.2 feet) than the 0.10 foot reported for the model, although it is not possible to make a scale comparison.

Little onshore-offshore movement was indicated during the field test. Some onshore movement of the first injection of gold-tagged sand is indicated in Figures 16, 17, and 18. However, after the second injection, shoreward movement of the offshore sand was obscured by the very rapid alongshore movement of the sand from the second injection. The survey made on 9 October indicates some seaward movement of tagged sand; high waves during 6, 7, and 8 October are judged the cause. Using fluorescent grains, Ingle (1966, page 189) found ". . . . in all cases, the majority of tracer grains traveled shoreward into the breaker zone although dispersion occurred in all directions". However, in Ingle's study of sediment movement immediately seaward of the breaker zone, sand was released 75 feet seaward of the breaker zone. During the RIST test, tagged sand was released along a line extending up to 350 feet beyond the breaker zone. Later, however, as a result of a storm and subsequent high waves on 7 October, the most seaward release point was in the breaker zone. By analogy then, the tagged sand should have been moved shoreward to the beach. The data do not show that this occurred.

Downcoast (lateral) movement is very evident, and during the initial surveys some slight upcoast movement of sand is evident, particularly on the beach face. However, rather sharp upcoast truncation of tagged sand is on all maps; it was not expected, but has been found in other RIST tests in nearshore areas. Such patterns appear to preclude the use of simple diffusion models to explain the dispersal of tagged grains.

Another point of interest is the location of zones of transport relative to the breaker zone. All maps depicted indicate the zone of breaking waves during the time of survey. Because of the tide and wave conditions, the seaward limit of breakers was at about -5 feet mean lower low water for the first survey of 5 October (Figure 18), and at about -6 feet from then to 7 October when the limit moved to about -12 feet. Movement of sand seems to be restricted to the zone of peaking, breaking and translatory waves.

Data also reveal zonal differences in relative rate of longshore movement. Survey data on 5 October (Figures 19 and 20) show that sediment at the landward margin of the breaker zone moved alongshore in about 3 hours the same, or greater, distance than that sediment seaward of that zone moved in 26 hours. Sediment on the beach face moved slower than sediment in the inshore zone, but faster than that in the offshore zone (seaward of the surf zone). Survey data on 9 October (Figure 21) indicate that much of the tagged sediment previously present in the inshore zone had moved completely out of the survey area. Ratios of count rate

indicate burial at the updrift end of the radioactive mass; particles released from these zones therefore would be few in number, and by downdrift dilution with untagged sand could escape detection. A relative rate of alongshore transport would be: inshore zone > beach face > offshore zone seaward of peaking and breaking waves. Sea and swell during the October series of experiments are summarized in Figure 23.

Mathematical simulation studies presently underway as part of the RIST program tend to fit the data observed in the field (W. R. James, personal communication). The observed difference in transport velocity is in direct agreement with the model tests conducted by Taney (1963) and the results of field studies reported by Ingle (1966). Studies by Komar (1969), which were confined to the beach face, imply greater velocity of sediment transport in the inshore zone than on the beach face.

In any sand-tracing experiment, knowledge of the depth and pattern of sand burial is important; it is fundamental to quantify littoral transport. Courtois and Sauzay (1966) present several theoretical models that, in general, follow a parabolic law and assume mixing (contrary to stratification) of the tagged sand with untagged "dead" sand. However, experimental results obtained in a later study (Courtois and Monaco, 1969) indicate burial offshore more closely follows an exponential law, and that stratification exists. Komar's (1969) beach studies (using fluorescent dyed sand) suggest an exponential type of burial law; that is, the depth of burial decreases exponentially with downdrift distance from the point of injection.

Short cores from the beach face obtained in this RIST experiment indicate stratification occurred, and tagged sand was overlain by dead sand. Core data is insufficient to contribute additional confirmation to the decrease in burial depth downdrift from a source. Ratios of the peak heights of the two radiation channels do tend to confirm a decrease in burial downdrift. Calibration of the detector system is still incomplete, so precise information about burial depth is still unknown. However, where count rate is of the same order of magnitude, computed ratios indicate decreasing depth of burial on the beach face with increasing distance from the source. Offshore, seaward of the outer line of breakers, the ratios are not significantly different, and this is now interpreted to mean little burial by "dead" sand, or at least shallow burial with mixing of tagged and untagged sand. Bed forms offshore in this area are slight ripples of sand overlying a firm sand bottom and are consistent with such an interpretation. Partially destroyed large ripples (6 by 4 by 1 1/2 feet deep) were also observed in the zone from -16 feet mean lower low water to the limit of observations at -20 feet mean lower low water. Waves and currents creating those features would be expected to cause deep burial and a consequent change in the radiation ratios.

During February 1969, another field test at Surf, California, was undertaken. The specific purpose was to obtain data on the pattern of

sediment transport during a different season and under different oceanographic climate. Long-range wave and weather forecasts indicated sea and swell conditions of 6 to 8 feet 90 percent of the time. These waves are within the operational range of the LARC XV amphibious vehicle. Based on preliminary analysis of the earlier September-October data, two simultaneous line injections of gold-tagged sand were made along Range 158 in depths of 6 to 14 feet mean lower low water and 21 to 27 feet mean lower low water. Returning to shore after injection, the LARC XV developed mechanical problems which could not be repaired at sea nor on the beach. Tracing components had to be transferred to the backup LARC V. Sea and breakers then rose to heights of 12 to 16 feet and stayed that high until the field study was terminated several days later. These high waves prevented safe operation of the backup vehicle in the sea, and tracing was confined to the beach. Tracing data indicated the tagged sand did not return to the beach.

Static tests with the mobile detector were conducted to determine, empirically, the ability of the system to detect burial based upon attenuation of gamma photons emitted by the gold. Small quantities of tagged sand were buried at 10-, 6-, and 3-inch depths and covered with dead sand. The spectrum obtained, readout and photographed at the site, is shown in Figure 24.

Section IV. COMPARISON OF THE RIST SYSTEM WITH OTHER ARTIFICIAL TRACING METHODS

1. General

Discussions of sediment tracing experiments invariably generate comparisons of particular programs, or comparisons between specific aspects of particular programs. Kidson and Carr (1962) present an excellent summary of methods used in marking beach sediments for tracing experiments. The purpose of this section is to relate the RIST study to other sediment-transport studies, to review reported transport-study methods, and briefly describe their procedures and scope.

Artificial tracers may be grouped into two major categories: stable and radioactive. In either case, the tracers represent particles that are placed in an environment selected for study, and are used for relatively short-term studies of sediment dispersion. Stable particles consist of crushed colored glass, crushed bricks, and anything else that is unlike the natural sediment. Naturally occurring sedimentary material, painted or coated with a bright paint or fluorescent dye, has also been used to study sediment transport (Ingle, 1966; Stuiver and Purpura, 1969). Activity may be induced in radioactive tracers in a number of ways. Labeling may involve neutron activation of an element in a mineral; for example, phospherus-32 prepared by this method was used with limited success on the California coast (Inman and Chamberlain, 1959). Radioactive material has been placed in holes drilled in a large pebble. It has beer incorporated in molten glass which, when hardened, is crushed

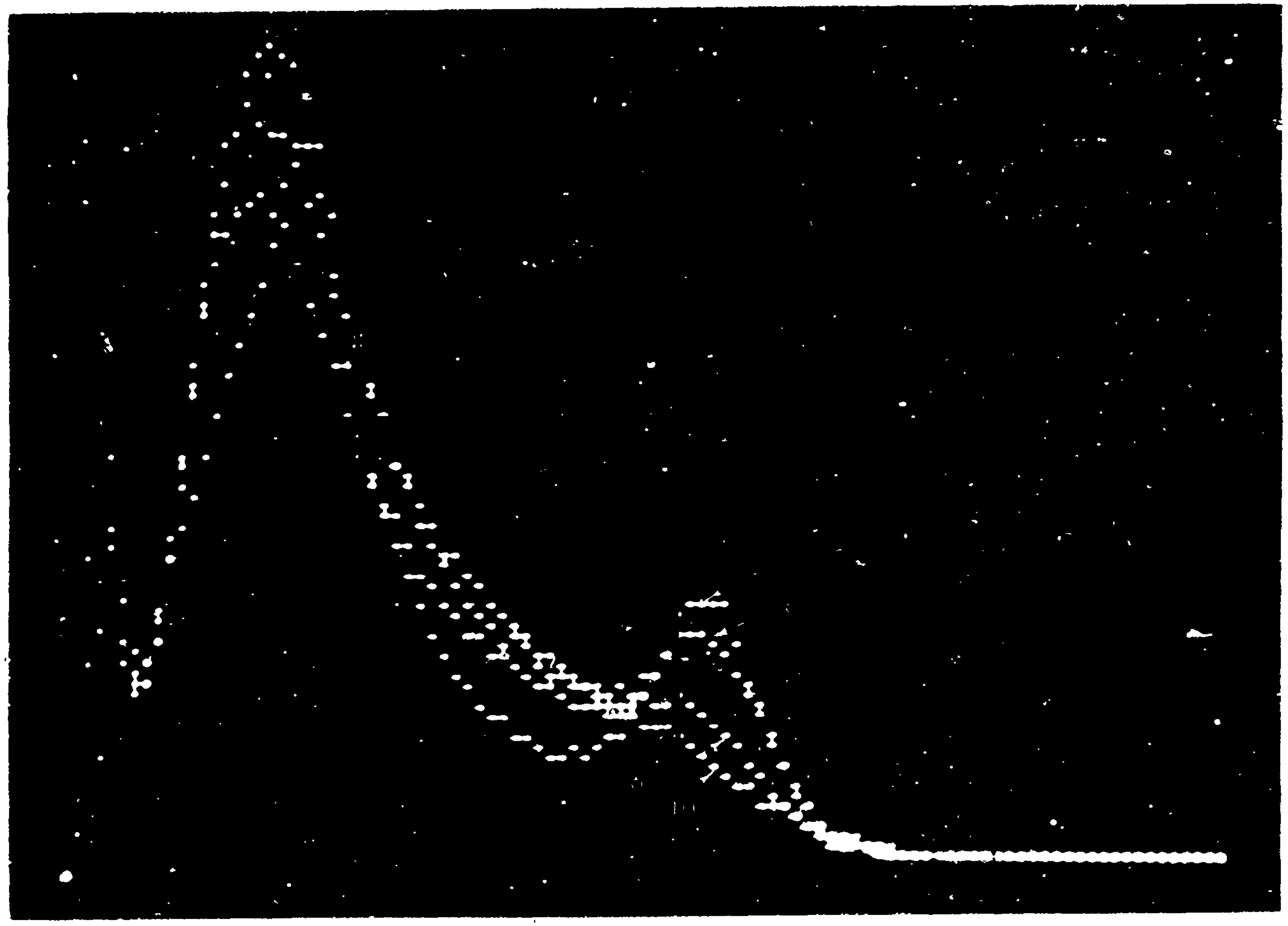


Figure 24. Changes in radioactive gold 198-199 spectrum resulting from burial by non-radioactive (dead) sand. Numbers indicate overburden thickness.

and resized (Sato, 1962; Taney, 1963). Radioactive material has been plated on the surface as in the ORNL-developed gold technique utilized in the RIST program. Radioactive gas (Krypton 85 and Xenon 133) has been absorbed into quartz sand (Chleck, et al., 1963; Acree, et al., 1969).

While particular experiments employ specific sampling methods and operational characteristics, there are basic elements in all tracing studies. These are: (1) selection of a suitable tracer, (2) tagging the particle, (3) placing the particle in the environment, and (4) detection of the particle, either *in situ* or in a laboratory after removal from the field location. For stable tracers, except in clear water or on a beach at low tide, samples of the sediment must be removed from the environment before the particle can be accurately detected. Collection of the data requires physically counting or weighing the sediment grains. In either nuclide or nonnuclide tracing, the particular particle must be detected. With fluorescent pigments, the detection is normally accomplished by an ultraviolet lamp. Sensitivity of this technique is usually reported to be about 1 part in 10 million of the sample examined. However, results are very dependent on the extent to which the field area being studied can be sampled. Since dilution of the tracer with natural sediment occurs rapidly, sampling is difficult. As a result, most studies using a fluorescent material are restricted to short periods of several hours. Also the number of samples that can be collected and processed is limited because manual sampling and laboratory analysis are time consuming. An automated device for counting fluorescent particles, described by Teleki (1967) apparently has not had widespread use.

When a radionuclide is used as the tracer, it is possible to detect it at the field site. The xenon-133 isotope-tagging technique was developed specifically for the RIST program, and is totally new to the field of sediment tracing. Gold-198 has been used numerous times in the past, especially in studies to determine the dispersal pattern of silts and clays. However, the gold-tagging technique developed for RIST (Stephens, et al., 1969) is greatly improved since the tag is firmly fixed to the grain so that detection of the isotope definitely shows that a tagged sediment particle has been detected. The same statement cannot be made with assurance for the previous gold-tagging techniques. In all studies reported, a sled device was used to carry the radiation detector over the bottom of the water body. Detectors are Geiger-Müller tubes or scintillation crystals. The collected data are on a continuous strip chart, although in some cases digital printout has been used (Hart, 1969; Courtois and Monaco, 1969). The field technique for locating the position of the detector sled, or more specifically, the vessel towing the sled, has been by the usual surveying technique, when on a given signal, two men operating surveying instruments read an angle of sight to the vessel. This information is recorded and later drafted by hand.

2. Comparison of RIST to Other Sediment Transport Studies

(a) Radionuclide Systems. In addition to investigation in the United States, radionuclide tracing technology is actively pursued by the French, Japanese, British, and Australians. Rather than review all of the reported studies, representative studies have been selected for description and consequent comparison to the RIST program.

Perhaps the best known of the British studies was reported by Crickmore and Lean (1962). This study was carried out in laboratory flumes with the goal of modeling sediment movement and providing a formula for quantifying results. Geiger-Müller tubes, buried in the flume, were used to detect radioactive sand moving in ripples over the detectors. Results of the studies are presented as a formula which provides the quantity of sediment moving as deduced by the time-integration method.

Studies by the French (Courtois and Monaco, 1969) are similar to the field programs of the British, Australians, and Japanese. These generally involve a sled-type detector carrying one or two scintillation detectors. In the French program, the sled carried two scintillation detectors with a sensitivity of 1 microcurie per square meter. Sand grains were tagged by the adsorption and consequent oxidation of chromium-51 on the surface of the grains; 10 pounds of sand were tagged with a total of 10 curies. Radiation was recorded on a strip chart and later by digital printout. The test was carried out on the French Mediterranean Coast in water 12 to 15 feet deep. All surveys of sediment dispersion from a point source were seaward of the breaker zone. Location of the vessels during the surveys was obtained by the cutoff angle technique described previously; angles were determined at 1-minute intervals. No information is provided with regard to the number of profiles or the length of time involved in each survey; however, the contoured area covers a rectangle 360 by 1,200 feet. Three surveys were conducted over a period of 1 month. Qualitative and quantitative results of the study are reported. Qualitative results are provided by a map which shows the dispersion of the tagged material during the survey. A quantitative analysis of the survey was made by using a radiation-material balance to determine depth of burial (correlated with some core data) which was then coupled to the displacement of the computed center of gravity of the moving mass of tagged sand.

The U. S. Army Engineer Waterways Experi .t Station (WES) at Vicksburg, Mississippi, recently completed a survey in the Houston Ship Channel (Hart, 1969). This study in the Galveston, Texas, area is the most recent research in sediment tracing reported by WES and is one of the most up-to-date of the radionuclide tracer studies in the United States. It is also representative of several previous WES programs. The isotope reported used was gold-198 which was mixed in solution with sediment at the site. Tagging occurred by simple adsorption by fine-grained sands. About 4 cubic feet of sediment were treated with a total

radioactivity of 4 curies; the tagging efficiency was not reported. The survey was essentially a zigzag pattern in the ship channel, and covered a track about 1,000 feet wide and 8 miles long. The detector vehicle was a sled that carried one scintillation counter with a sensitivity of 6,000 counts per minute per microcurie per square foot. Radioactivity was recorded on an analog strip chart; counts were accumulated over a 10-second period. Location of the towing vehicle was determined by the cutoff angle technique at 2-minute intervals. The experiment lasted 1 week; one survey was made each day. Method of data reduction is not stated, but it is assumed to be essentially by manual computation. Results - only qualitative - are shown as a diagram indicating the presence and level of radioactivity versus distance along the channel. Other WES programs of this type have been conducted in San Francisco Bay, The Galveston area and in Charleston, South Carolina.

(b) Fluorescent Systems. In the United States more studies using fluorescent dyes have been reported than those using radioisotopes. Although most studies are at beaches, some have been made of river transport.

The United States Geological Survey (USGS) recently prepared an open-file report on sediment discharge at Clear Creek, Colorado (Kennedy and Kouba, 1968). In this investigation, dyed sand was introduced at a constant rate at a point for a period of 28 hours. Samples were obtained from a point near the stream bed 1/2 mile downstream. In this USGS study, three fractions of different sizes of the sand carried by the river were dyed with different colored fluorescent material. During the experiment, 0.2 pound (90 grams) of each size fraction were injected every 3 minutes for 28 hours. About 300 pounds of sand were used. The stream was sampled continuously during the test. Samples were dried and sieved. Each size fraction was placed in a vibrating-feeder device with a spiral trough, and observed under ultra-violet light so that the number of fluorescent grains could be recorded with a manual counting device. Results of the program are quantitative, based on the Crickmore and Lean constant-injection technique.

At the University of Florida, the Department of Coastal and Oceanographic Engineering has been experimenting with fluorescent tracing in the marine environment for several years. In their beach studies, the experiments have generally been carried out between the high- and low-tide line. In a recent study (Stuiver and Purpura, 1969), material was injected as a band 50 feet wide from the high-tide line to the low-tide line with additional sand placed in water-soluble bags to a 3-foot depth. Samples were obtained along ranges spaced 500 feet apart; three samples were collected along each range. After the samples dried, they were split into 100-gram parts which were then counted to give the concentration of fluorescent particles as the function of distance from the injection line. The experiment lasted about 45 days, and samples of tagged sand were obtained as far as 5,000 feet downcoast. In addition to the studies at the beach, the University of Florida scientists studied sediment

dispersion at an inlet. In this study, 2,000 pounds each of 4 colors of dyed sand were used. The study area was sampled periodically for about 1 month with samples obtained along ranges spaced at 100-foot intervals. Results of both of these studies were qualitative only.

Recently, the Scripps Institute of Oceanography (Komar, 1969) reported the results of using fluorescent tracers through three beaches, two of which were in Southern California. In general the area studied extends from the plus 3-foot contour to the minus 3-foot contour, with sand injected as a band of sediment raked into the beach face at low tide. Where the sand had to be placed through the water column, the sand was packaged in paper bags; these were manually broken open after placement on the bottom. Between 70 to 200 samples were recovered from an area about 200 by 1,000 feet; 100 to 200 pounds of sand were used. Results were expressed as maps showing number of grains of tracer per kilogram. Volume samples (grab) were obtained rather than surface samples (greased card), usually obtained in fluorescent studies. In the results reported, samples were usually obtained only once for each test. At Silver Strand Beach (south of San Diego) five tests were conducted. The maximum elapsed time from tracer injection to sampling and conclusion of the survey was 4 1/2 hours; usual duration was 1 hour. Results expressed are qualitative and quantitative. However, the quantity of sand moving must be considered a minimum because the maps resulting from the study show marked truncation at the seaward limits of the sample zone with indications that maximum transport occurs seaward of the low-tide line. The RIST study has confirmed that the maximum velocity of transport is in the inshore zone, not on the submerged foreshore.

Perhaps the most widely known and most often quoted work on fluorescent tracers is that by James C. Ingle (1966). In his research, Ingle investigated five California beaches; the areal extent studied was about the same in all cases. At Trancas Beach, west of Los Angeles, samples were collected as much as 3 hours after injection of the tracer; this was the longest study. In all studies, packets of tagged sand were placed at specific intervals along a line seaward from the beach backshore. At Trancas, six packets of sand weighing 5 pounds each were placed at 25-foot intervals along the line from mean sea level to a depth contour of 4 feet below mean lower low water. In all, only 57 data points were sampled over a rectangular area 200 by 850 feet; a total area of 170,000 square feet. The 57 data points, each represented by a 9-square inch sample (3- by 3-inch greased card) cover a total area of 3.56 square feet. This sampled area represents 0.000021 of the total area on which to base contours of grain count.

In the following paragraphs, data on the RIST test at Surf, California in October 1968 are used for a comparison with some of the studies briefly reviewed above. On 4 October 1968, in a period of 44 minutes, an area 900 by 1,300 feet (more than 1 million square feet) was surveyed. The survey started 2 hours after injection of the isotope, and extended from the plus 3-foot contour to about the minus 15-foot contour. In the course

of the study, 1,300 data points (collected at 2-second intervals) were analyzed; and about 20,000 square feet (10,000 feet of track times a 2-foot width visible to detector), or .017 of the area mapped, were actually sampled. On 9 October (Figure 20), a rectangular area 3,300 by 1,600 feet (in excess of 5 million square feet) was surveyed in less than 2 hours - 126 hours after injection of the isotope. The survey extended from +6 feet on the beach to -15 feet seaward of the surf zone. All told, 3,000 data points were collected over a track nearly 20,000 feet long. That track length represents examination of nearly 40,000 square feet of the area represented by the map or about 0.0075 of the total area. A more significant comparison of the RIST data and that of Ingle's study is illustrated on Figure 25. The paper by Courtois and Monaco (1969) does not indicate the number of data points, but the dimensions of the dispersing mass of sand can be determined from the maps illustrated. For comparison purposes the larger pattern is also illustrated on Figure 25.

A search of literature shows no other studies have synoptically examined the beach face, inshore zone, and the offshore bottom. Other reported studies are confined to a beach face or deep water (a harbor, a bay, or the ocean seaward of the surf zone). The earlier inability to look at the inshore zone, the zone of maximum transport, has been due to the detection vehicles and detector systems that were not rugged enough to withstand the extreme forces of the surf zone. The ball-type detector developed for RIST solves this problem. However, the general technique of towing the detector vehicle over the sediment-water interface where sediment transport is taking place is common between the RIST system and other radioisotope tracer systems. Use of a 4-detector array provides a high degree of sensitivity, increases detection capability, and examines a larger area, and thus improves the counting statistics. The RIST data acquisition system, which automatically collects and correlates time, position, and radiation counts, is unique in the field of sediment tracing.

Section V. SUMMARY

Studies carried out at Surf, California, indicate the suitability of the techniques and technology developed in the RIST program for simultaneously tracing sediment on a sand beach, through the surf zone, and to the offshore bottom beyond. Sand labeled with the radioisotope of gold 198-199 provides much more data for analysis of sediment movement than does sand labeled with xenon-133. In respect to collected data, gold is considered to be superior to xenonated sand for field tracing purposes. Use of a multiple-photon isotope, such as the mix gold 198-199, coupled with a data collection system capable of discriminating between specific spectral levels, makes it possible to determine relative depths of burial, provided labeled sand is overlain by "dead" sand.

Surveys conducted confirm that, in response to any given set of wave conditions, a very different rate of sediment movement occurs in

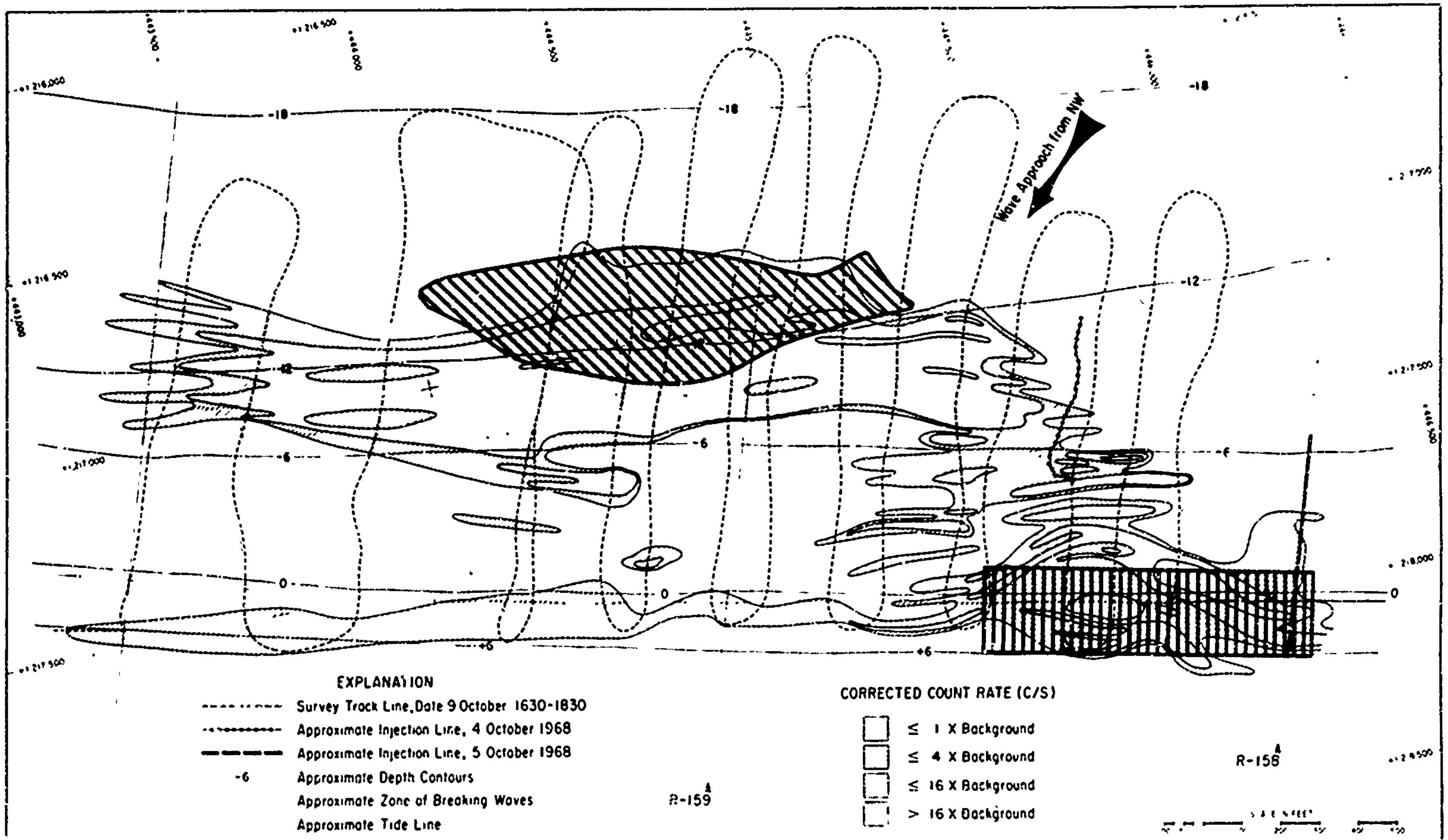


Figure 25. Comparison of tagged sand dispersal patterns. The base map is the RIST survey of 9 October 1968 with gold as the sand label. The rectangular area in lower right, drawn to same scale as the base and positioned environmentally, represents the study by Ingle (1966) on Trancas Beach, near Los Angeles. The crudely fish shaped area in the upper center, drawn to the same scale as the base and positioned environmentally, represents tagged sand dispersal pattern reported in the study of Courtois and Monaco (1969); elapsed time of the study approximately 30 days

the zones between the high-tide line and -15 feet mean lower low water. Because of these differences, tracing surveys confined solely to the foreshore or offshore zone produce data only partially indicative of transport in the zone of immediate concern to coastal engineers. The indicated differing rates of transport, coupled with different depths of sediment movement, add complexities to the realistic determination of quantities of sediment movement. Observed patterns of sediment movement indicate that previously used methods for solving the problem of volume sediment transport, such as displacement of the center of gravity of the tagged mass, simple dispersion models and random walk models, are not adequate. While an accurate determination of sediment drift volume remains illusive, qualitative data on sediment movement useful for engineering purposes can be obtained on a scale heretofore unattainable. Data obtained with the RIST system can be treated as synoptic observations of sediment transport in several adjacent environments. Qualitative sediment transport data of the type now possible to obtain through RIST have application in the studies of such engineering works as: (1) the behavior of a groin; (2) the functioning of a "weir-jetty", and (3) shoaling harbors.

Research and development toward improving the RIST program continue, including improvement of data handling programs, quantification of drift measurements, and field tests on other sites. All are designed to make the system a more efficient engineering and research tool.

LITERATURE CITED

Acree, E. H., Case, F. N., Cutshall, N. H., and Brashear, H. R. (1969) "Radioisotopic Sand Tracer Study (RIST) Status Report for May 1966-April 1968", ORNL-4341, Contract No. W-7405-eng-26. Oak Ridge National Laboratory, operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

Bagnold, R. A. (1947), "Sand Movement by Waves: Some Small-Scale Experiments with Sand of Very Low Density", *Journal, Institute of Civil Engineers*, London, Paper 5554, pp. 447-469.

Berg, D. W. (1968), "Systematic Collection of Beach Data", *Proceedings of the 11th Conference on Coastal Engineering, American Society of Civil Engineers*, p. 273-297.

Chleck, D., Maehl, R., Currihiara, O., and Caunrevale, E. H. (1963), "Radioactive Kryptomates", *International Journal of Applied Radiation and Isotopes*, Vol. 14, pp. 581-610.

Courtois, G. and Monaco, A. (1969), "Radioactive Methods for the Quantitative Determination of Coastal Drift Rate", *Marine Geology*, Vol. 7, pp. 183-206.

Courtois, G and Suazay, G. (1966), "Count Rate Balance Methods Using Radioactive Tracers for Measuring Sediment Mass Flows", *Houille Blanche* 3: 279-290.

Crickmore, M. J. and G. H. Lean (1962), "The Measurement of Sand Transport by Means of Radioactive Tracers", *Proceedings, Royal Society (London)* A266:40221, 1962, Nuclear Science Abstract 16:16588, 1962.

Cummins, R. S. (1964), "Radioactive Sediment Tracer Tests, Cape Fear River, North Carolina", Miscellaneous Paper No. 2-649, May 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Duane, D. B. and Judge, C. W. (1969), "Radioisotopic Sand Tracer Study, Point Conception, California, Preliminary Report on Accomplishments, July 1966 - June 1968", U. S. Army Coastal Engineering Research Center, Miscellaneous Paper 2-69.

Hart, E. D. (1969), "Radioactive Sediment Tracer Tests, Houston Ship Channel, Houston, Texas", U.S. Army Engineer Waterways Experiment Station H-69-2, pp. 1-14.

Ingle, J. C. Jr. (1966), *The Movement of Beach Sand*, Elsevier Publishing Co., Amsterdam, Holland.

Ingram, L. F., Cummins, R. S. and Simmons, H. B. (1965), "Radioactive Sediment Tracer Tests Near the North and South Jetties, Galveston Harbor Entrance", U. S. Army Engineer Waterways Experiment Station, Miscellaneous Paper No. 2-472.

Inman, D. L. and Chamberlain, J. K. (1959), "Tracing Beach Sand Movement with Irradiated Quartz", *Journal of Geophysical Research*, Vol. 64, No. 1, pp. 41-47.

Kennedy, V. C. and Kouba, D. L. (1968), "Fluorescent Sand as a Tracer of Fluvial Sediment", U.S. Geological Survey open-file report, 53 pp.

Kidson, C. and Carr, A. P. (1962), "Beach Materials for Tracing Experiments", *Journal of the Hydraulics Division, American Society of Civil Engineers*, Vol. 88, No. HY4, pp. 43-60.

Komar, P. D. (1969), "The Longshore Transport of Sand in Beaches", Scripps Institute of Oceanography, Ph. D. dissertation, 143 pp. (unpublished)

McArthur, D. S. (1969), "Sand Movement in Relation to Beach Topography", Coastal Studies Institute, Louisiana State University, T.R. No. 67, 26 pp.

Pirie, R. G. (1965), "Sediment Rate of Granule- and Pebble-sized Clasts", *Proceedings, 8th Conference on Great Lakes Research*, Pub. No. 13, Great Lakes Research Division, University of Michigan, pp. 232-239.

Sato, S., Takeshi, I., and Tanaka, N. (1962), "A Study of Critical Depth and Mode of Sand Movement Using Radioactive Glass Sand", *Proceedings of the 8th Conference on Coastal Engineering*, Council on Wave Research, University of California, Berkeley. pp. 304-323.

Stephens, N. H., Acree, E. H. and Case, F. N. (1968), "Evaluation of Four Methods using Gold-198 for Surface Labeling Sand and a New Technique for Simulating Mass Labeling", Oak Ridge National Laboratory Report ORNL-4338, p. 9.

Stuiver, M. and Purpura, J. A. (1968), "Application of Fluorescent Coastal Sand in Littoral Drift and Inlet Studies", *Proceedings, 11th Conference on Coastal Engineering, American Society of Civil Engineers*, pp. 307-321.

Szuwalski, A. (1970), "Littoral Environment Observation Program in California, Preliminary Report, February-December 1968", U. S. Army Coastal Engineering Research Center, Miscellaneous Paper 2-70.

Taney, N. E. (1963), "Laboratory Applications of Radioisotopic Tracers to Follow Beach Sediments", *Proceedings of the 8th Conference on Coastal Engineering*, Council on Wave Research, University of California, Berkeley, pp. 279-303.

Teleki, P. G. (1967), "Automatic Analysis of Tracer Sand", *Journal of Sedimentary Petrology*, Vol. 37, pp. 749-759.

Turner, P. A. (1970), "RAPLOT, A Computer Program for Processing and Graphical Display of Radioisotopic Sand Tracer Data", U. S. Army Coastal Engineering Research Center, Miscellaneous Paper 3-70.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Coastal Engineering Research Center (CERC) Corps of Engineers, Department of the Army Washington, D. C. 20016	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

TRACING SAND MOVEMENT IN THE LITTORAL ZONE: PROGRESS IN THE RADIOISOTOPIC SAND TRACER (RIST) STUDY - July 1968-February 1969

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

David B. Duane

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1970	52	25

8a. CONTRACT OR GRANT NO. AT(49-11)-2988 between Atomic Energy b. PROJECT NO. Commission and Coastal Engrg Research Center c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper 4-70 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Tagging procedures, instrumentation, field surveys and data handling techniques have been developed by the radioisotopic sand tracing study for the collection and analysis of over 12,000 bits of information per hour over a survey track of about 18,000 feet. Data obtained can be considered as nearly synoptic observations of sediment transport in a single environmental zone or in adjacent beach, surf and offshore zones. Experiments at Surf, Point Conception, Point Mugu, and Oceanside, California, used sand tagged with isotopes of xenon or gold. Data from studies in beach areas unmodified by littoral barriers indicate that the alongshore velocity of sediment transport differs from zone to zone. Transport seaward of peaking, breaking waves is less than transport on the beach face which is less than transport in the plunge and surf zone. Zone dimensions change with waves and tides. Tracing surveys confined to the foreshore or offshore zones produce data only partly indicative of transport in the zone of immediate concern to coastal engineers. Studies conducted at the site of shore structures indicate the RIST system can provide data useful in understanding the effect of such structures on sediment transport.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dynamic Oceanography						
Sediment transport						
Littoral processes						
Sediment tracers						
Sediment analyses						
Hydrographic surveys						
Radioisotopes						
Xenon-133						
Gold 198-199						
Radiation detector						
Cesium iodide crystals						
Automatic Data Processing						
Headlands						
Beaches						
California						

UNCLASSIFIED
Security Classification